Biochar from Construction & Demolition Waste

Environmental Alternatives for Landfill Diversions

5280 Recycling Solutions

Denver, Colo.

A New Enterprise & Product Business Plan

As A Capstone Project Submitted by

Melissa Baldridge

In Candidacy for a Master's Degree in Sustainability (ALM)

Harvard University

Aug. 20, 2020

Table of Contents

(cont.)

Tables & Figures

Mission Statement

Partnered with sister company, 5280 Waste Solutions, 5280 Recycling Solutions saw both value and environmental benefit in single-stream construction and demolition ("C&D") recycling by diverting materials like wood, asphalt shingles, and gypsum drywall from landfill.[1] So, the company set two goals for itself:

1. **Single-Stream Hauling** – The company decided to be first in the state of Colorado to have single-stream C&D waste hauling rather than having construction clients sort on site.
2. **Recycling Solutions** – The company decided to be the market leader in finding solutions for creating value in secondary use/recycling of C&D waste.[2]

5280 Recycling Solutions' Mission – *Create a thriving business while doing what's right.*[3]

Code of Conduct

Melissa Baldridge (the "Consultant") is delivering this business plan for end-market, end-buyer development, and product launch of biochar and any other 5280 companies'-designated wood-derived products backed by solid research and validation from retailers, consumer groups, industry professionals, researchers, and end users. Ms. Baldridge worked directly with 5280 Recycling Solutions Chief Operating Officer Laurie Johnson, and any interactions with employees or owners of the 5280 companies and outside parties were conducted with care, respect, attention, integrity, and professionalism.

Background

5280 Recycling Solutions ("the Company") is a business-to-business waste management company working in the Front Range of Colorado (metro Denver area, and north and south along Interstate Highway 25)[3]. The Company works with and was spawned from sister company 5280 Waste Solutions in 2017 to find ways to reduce, reuse, and recycle waste – specifically C&D waste from commercial and residential building, development, and LEED green-building clients.[4]

---

[1] (5280 Recycling Solutions, 2019)
[2] (5280 Recycling Solutions, 2019)
[3] (5280 Recycling Solutions, 2019)
[4] (5280 Recycling Solutions, 2019)

The Company's Vision

The Company's vision is to create viable, profitable, and circular-economic products diverting C&D waste – wood, gypsum drywall, and asphalt shingles – from landfill, keeping the materials at highest value through subsequent reuse(s).

a. **Recycled, Circular Products** – The Company creates and sells biochar from wood waste, thus diverting it from landfill.
b. **Carbon Sequestration** – When possible, the Company creates carbon sequestration "sinks" through sale and application of its biochar.
c. **Green-Building** – The Company "increases recycling options for companies looking to gain LEED status on a project or wanting to document a recycling or diversion percentage for a project."[5]
d. **Jobs** – The Company "wants to create local jobs with skills training."[6]

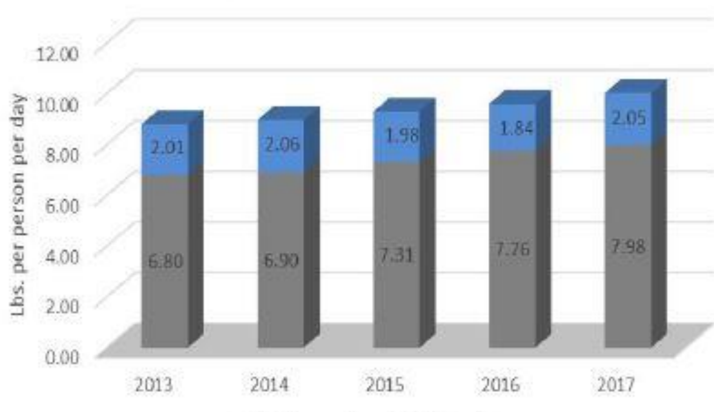
The Problem

Municipal Solid Waste (MSW) – Colorado is known for being environmentally friendly, but when it comes to trash, it is anything but.[7] Colorado has a landfill diversion rate that's 20 percent, and the national average is 34 percent (recycling and composting).[8] That translates to more than 10 pounds per person, per day.[9] What's worse, that per-capita waste generation rate has been rising over the past six years[10] (see Figure 1).

---

[5] (5280 Recycling Solutions, 2019)
[6] (5280 Recycling Solutions, 2019)
[7] (Brown, 2018)
[8] (Hazardous Materials and Waste Management Division, 2019, p. 14)
[9] (p. 15)
[10] (p. 15)

Figure 1 - Per Capita Waste Generation in Colorado



(Hazardous Materials and Waste Management Division, 2019, p. 15)

Construction & Demolition Waste – One of the biggest components of MSW is C&D waste – gypsum drywall, asphalt shingles, and wood (both treated and untreated). Estimates place Denver's C&D waste as 20 percent of total MSW[11]. The estimate for the state's "construction and industrial" materials is 40 percent,[12] and Pitkin County's (Aspen, Colo.) C&D rate is 62 percent.[13] All this is set against the economics of trash hauling in Colorado and in metro Denver. Standard C&D tipping fees cost $25 per ton, yet a manual sorting process costs more than three times that - $80 per ton.[14]

The Company tips between 200 to 300 three-ton dumpsters of C&D waste into landfill every day, totaling 1.2 million pounds or 600 tons.[15] Mr. Bradley formed the Company in 2017 to divert as much C&D waste from landfill as possible by creating high-value end products and markets.[16] As of this writing, there is no mechanized sorting facility (MRF, materials recycling facility) on Colorado's Front Range so, recycling sorting must currently be manual. The Company is a limited liability company (LLC), a common legal structure in Colorado because of its liability shield and potential tax advantages.[17]

[11] (Brown, 2018)
[12] (Cottom, 2018)
[13] (Brown, 2018)
[14] (Laurie Johnson, personal communication, July 15, 2019)
[15] (Laurie Johnson, personal communication, April 23, 2020)
[16] (Laurie Johnson, personal communication, July 15, 2019)
[17] (Watson & Associates, LLC, n.d.)

<u>Problem Statement</u>— Colorado lags in recycling both MSW and C&D waste because tipping fees are low, and land plentiful and cheap for landfill. Wood waste comprises between 20 to 60 percent of C&D landfill loads in Colorado because it has no back-end value. Mechanized sort centers are currently non-existent for C&D, and end markets for recycled, circular C&D-derived products are under– and undeveloped.

This linear C&D materials stream (forest to building, and ultimately to landfill) is grossly inefficient, adds greenhouse gas landfill emissions with climate and human health impacts, and does nothing to reduce the need for virgin wood products, which in turn reduce carbon-sequestering forests at a time when they're needed most.

Metro Biochar® can solve some or all of these problems by diverting wood from landfill, providing water filtration and toxic remediation solutions, and even sequestering carbon.

Biochar – The Product

Biochar History – What's Old Is New – Biochar has been lately rediscovered, but its creation and use actually span back millennia to the middle of the Amazon rainforest.[18] Amerindian farmers added biochar to fish bones and other organic materials to fertilize highly acidic soils, resulting in what the Portuguese later called *terra preta* ("black earth").[19] Early farmers in Japan, South America, and Africa also used *terra preta* as a soil amendment.[20]

Definition – Biochar is defined as "a solid material obtained through the thermochemical conversion of biomass in an oxygen-limited environment."[21] Biochar can be made from a number of waste streams, including agricultural, forestry ("slash"), industrial waste, municipal sludge (into biosolids), and MSW.[22] *For purposes of the Company's plan, woody biomass from C&D clean wood waste is the biochar feedstock, "the material undergoing thermochemical processes to create biochar," considered here.*[23]

---

[18] (Galinato, Suzette P.; Yoder, Jonathan K.; Granatstein, David, 2011, p. 6344)
[19] (eXtension, 2019)
[20] (eXtension, 2019)
[21] (Koper, et al., 2010, p. 6)
[22] (Koper, et al., 2010, p. 7)
[23] (Koper, et al., 2010, p. 8)

There is no strict taxonomy for pyrolyzed biomass, and terms like “char,” “charcoal,” and “activated carbon” are used interchangeably.[24] *The defining characteristic of biochar compared to other materials is that carbon sequestration is either a goal or a knock-on effect.*[25] *Additionally, the intended application is non-oxidative, sustainably sourced (from biomass, not fossil-fuel feedstock), with carbon content greater than 50 percent (>50%), and a low level of pollutants as outlined in the European Biochar Certificate guidelines.*[26] Any biochar removed after initial use, e.g., for waste or hazardous material cleanup, is technically not biochar.[27] See Table 1 for more detailed definitions of various carbonaceous materials.

Characteristics & Uses – Biochar has a number of beneficial, unique, and promising characteristics. That said, the catch phrase for biochar’s attributed benefits is “*it depends*.”[28,29] All sorts of variables impact agricultural results, including climate zone, soil type and pH, and crop choice.[30,31] While benefits described here are cited, sources should be consulted for specific details, crops, and applications.

[24] (Hagemann, et al., 2018, p. 182)
[25] (Hagemann, et al., 2018, p. 182)
[26] (Hagemann, et al., 2018, p. 182)
[27] (Hagemann, et al., 2018, p. 183)
[28] (Greg Litus, Ph.D., personal communication, July 20, 2020)
[29] (Galinato, Suzette P.; Yoder, Jonathan K.; Granatstein, David, 2011, p. 6345)
[30] (Galinato, Suzette P.; Yoder, Jonathan K.; Granatstein, David, 2011)
[31] (Ramlow, Foster, Del Grosso, & Cotrufo, 2019)

Table 1 - Definitions of Various Carbonaceous Materials, Properties, Uses & Market Data

CARBONACEOUS MATERIALS PROPERTIES, USES & MARKET DATA

TYPE	DEFINITION	PROPERTIES & CHARACTERISTICS	DIFFERENTIATORS	USES	MARKETS	CIRCULAR PROCESS	CARBON-SEQUESTERING
Biochar (B)	Material produced through pyrolysis of biomass.[3]	High carbon content and surface area, high cation/anion exchange capacity, and a stable structure.[1] B must be used in non-oxidative applications for carbon sequestration (e.g., soils, as in agriculture or industry), from sustainably sourced biomass that do not include fossil fuels, and have distinct chemical properties like >50% carbon.[2] B is stable in soils for decades and even centuries.[2]	Both B and AC are *pyrogenic carbonaceous materials (PCM).*[2] B often referred to as "charcoal," but it's differentiated from Ch. More efficient at removing heavy metals than AC.[1]	***Carbon sequestration a goal or indirect effect of all biochar applications.***[2] (1) Soil remediation and amendment[2] (2) Used in biodegradable packaging (3) Concrete amendment to reduce amount of cement or sand needed (4) Raw material for electrodes in microbial fuel cells (5) Tertiary treatment of wastewater (heavy metals)[1] (6) Used as a buffering agent in anaerobic digestion	$30MM annually[4]	**Y**	**M**
Charcoal (Ch)	Carbonized wood used mainly as smokeless fuel or a reductant in industrial processes.[2]	Oldest chemical product used 5,000 years ago.[2] Ch still largely produced crudely in earth mounds with no exhaust, thus venting VOCs, PM2.5, CO, and CH4.[2]	If burned as fuel, carbon becomes carbon dioxide and is characterized as Ch.[2] Added ignition accelerants can be toxic to plants.[5]	Carbonized wood burned as smokeless fuel source for heating, cooking, and steel production.[2]	50MM tons produced globally (2015). Appx. 25% of globally harvested wood converted to Ch, and two-thirds of that from Africa.[2]	**Y**	**N**
Char	Material from incomplete combustion of natural or anthropogenic origin that is sometimes synonymous with *pyrogenic organic matter (PyOM)*.[2]					**Y**	**N**
Activated Carbon ((AC), aka Activated Charcoal)	AC produced from any carbonaceous source (fossil, waste, renewable) and engineered for sorbency to remove contaminants from gases and liquids. Therefore, defined as a material for contaminant sorption ***without exigencies in regard to the sustainability of its production nor to the fate of the carbon after its use***."[2]	- Granular AC removes VOCs and chlorine Post-activation AC lacks continuous graphite sheet character from prior to activation.[2] Porosity of AC depends on many factors, including feedstock, temperature, duration of activation, process, and choice of oxidant.[2]	Both B & AC are *pyrogenic carbonaceous materials (PCM).* Considered biochar when (1) *not* removed after application, (2) *not* sourced from renewable feedstock, and (3) complies with other biochar specifications.[2]	Soil remediation, driinking water conditioning, energy storage technology, cleaning industrial processes (e.g., mercury from power plants).[2]	$3B per year - Powdered - 50% of total - Granular - 30% of total - Impregnated - 20% of total[2]	**M**	**M**

1 Enaime, G., Baçaoui, A., Yaacoubi, A., & Lübken, M. (2020, May 18). Biochar for Wastewater Treatment - Conversion Technologies and Applicatiopns. *Applied Sciences, 10* (10), 1-29. doi:10.33990/app10103492

2 Hagemann, N., Spokas, K., Schmidt, H.-P., Kägi, R., Böhler, & Bucheli, T. D. (2018, Feb. 9). Activated Carbon, Biochar and Charcoal: Linkages and Synergies Across Pyrogenic Carbon's ABCs. *Water, 10* (182), 1-19. doi:https://doi.org/10.3390/w10020182

3 Koper, T., Weisberg, P., Lennie, A., Driver, K., Simons, H., Rodriguez, M., . . . al., e. (2010). *Methodology for Biochar Projects.* Retrieved May 21, 2020, from American Carbon Registry: https://americancarbonregistry.org/carbon-accounting/standards-methodologies/methodology-for-emissions-reductions-from-biochar-projects/acr_tct_biochar-meth_public-comment-draft.pdf

4 U.S. Forest Service. (2018, Aug. 16). *Survey and Analysis of the US Biochar Industry Preliminary Report Draft: August 16, 2018.* Retrieved April 16, 2020, from USBI: https://biochar-us.org/sites/default/files/news-files/Preliminary%20Biochar%20Industry%20Report%2008162018_0.pdf

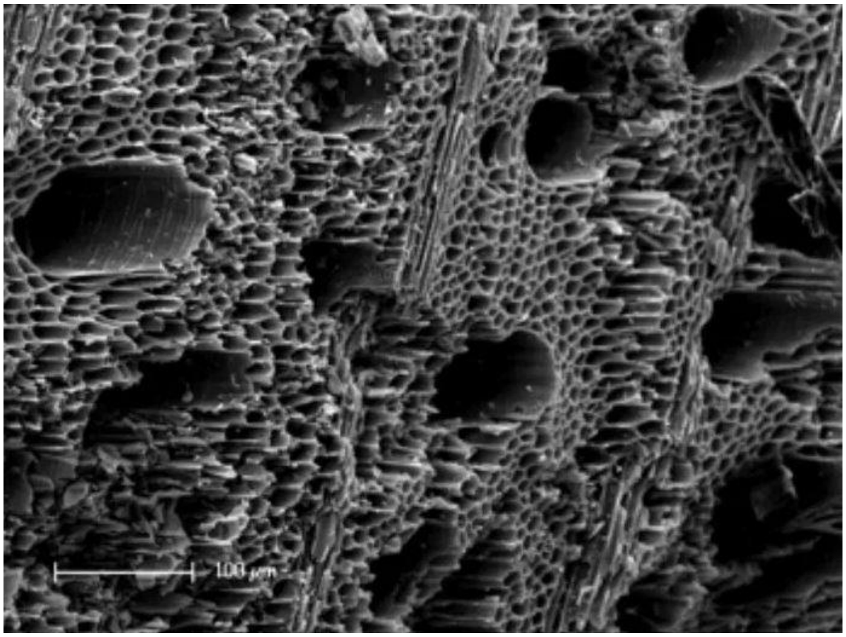
5 CharGrow. (2018, Oct. 13). *Biochar vs. Charcoal vs. Activated Carbon: What They Are & How They Work* . Retrieved June 23, 2020, from CharGrow: https://char-grow.com/biochar-vs-charcoal-vs-activated-carbon#:~:text=Biochar%20is%20intended%20for%20agricultural,biomass%20in%20a%20similar%20manner.

6 Merriam-Webster, Incorporated. (2020). activate. Retrieved July 27, 2020, from Merriam-Webster: https://www.merriam-webster.com/dictionary

DEFINITIONS: ***Activate*** *- To treat a substance (like carbon or alumina) so as to improve adsorptive qualities. Activation can add strength, total porosity, surface area and charge, and diffusivity.*[6] *Water is oxidant for carbonaceous materials and can physically activate them.*[2]

Biochar's Characteristics

Figure 2 - Biochar Under An Electron Microscope



(Pranitha, 2017)

- **High surface area** – One estimate states that when lignocellulosic mass is converted, the resulting biochar has a surface area of 300 $m^2 g^{-1}$ (or 3,229 square feet per 0.035 ounces)(See Figure 2).[32]
- **Organic matter** – Biochar efficiently removes organic matter from wastewater.[33]
- **Nutrient retention** – One soil column study shows that biochar increases total N (up to 7 percent), organic C (up to 69 percent), and (*Mehlich III extractable*) P, K, Mg, and Ca.[34]
- **Nutrient leaching** – One study shows biochar significantly reducing nutrient leaching (N, P, Mg, Si).[35]
- **Ion exchange** – Biochar has a high ion-exchange capacity.[36]
- **Microbial activity** – One study shows biochar stimulates soil microbial activity, especially mycorrhizal fungi.[37]
- **Oxygen uptake** – One industrial wastewater treatment study showed biochar outperformed granular activated charcoal (GAC) by 30 percent more *adsorption* for total chemical oxygen demand (COD_{-T}).[38]

[32] (Huggins, Haeger, Biffinger, & Ren, 2016, p. 4)
[33] (Perez-Mercado, Lalander, Berger, & Dalahmeh, 2018, p. 16)
[34] (Laird, Fleming, Wang, Horton, & Karlen, 2010, p. 441)
[35] (Laird, Fleming, Wang, Horton, & Karlen, 2010, p. 436)
[36] (Ramlow, Foster, Del Grosso, & Cotrufo, 2019, p. 72)
[37] (Laird, Fleming, Wang, Horton, & Karlen, 2010, p. 436)
[38] (Huggins, Haeger, Biffinger, & Ren, 2016, p. 10)

- **Lightweight and highly porous** – Biochar reduces bulk soil density and improves soil aeration.[39]

Biochar's Uses

- **Increases water retention** – Biochar can help soils retain water, crucial in water-stressed regions.[40] One study with Colorado maize showed biochar increased gravimetric soil water content by 9.7 percent and increased water retention by 7.4 percent [41] While this is important, the authors Ramlow et Al., say that the greater agronomic value is in helping crops reduce and withstand water stress.[42]
- **Sequesters & stabilizes carbon** – Woody biomass is carbon-stable and a prime candidate for carbon sequestration.[43]
- **Reduces greenhouse gases (GHGs)** – Slow-pyrolyzed wood-derived biochar can create annual GHG emissions *reductions* of 0.58 to 1.72 Mg $CO_{2\text{-eq}}$ ha^{-1} at a 25 Mg ha^{-1} biochar application rate (0.65 to 1.90 U.S. (short) tons per 2.47 acres, or *0.26 to 0.77 U.S. (short) tons per acre*).[44] If feedstocks are sustainably sourced, biochar can deliver GHG benefits up to 12 percent of annual, global anthropogenic $CO_{2\text{-eq}}$ per year.[45]
- **Resides in soils at century(-ies) scale** – A large part of the fixed carbon in biochar resides in soils in excess of 100 years or longer.[46,47]
- **Boosts crop yields** – Some studies show biochar increasing crops yields as much as 51 percent.[48] When compost is mixed with biochar, a thin organic coating forms, which helps the material store nutrients and form other organic matter.[49]
- **Reduces N_2O emissions** – Woody biochar reduces N_2O emissions consistently with minimal impacts across soil types or N fertilizer addition.[50] While not studied in the field, N_2O emissions dropped as much as 54 percent in one study with lab incubations.[51]

---

[39] (eXtension, 2019)
[40] (eXtension, 2019)
[41] (Ramlow, Foster, Del Grosso, & Cotrufo, 2019, pp. 71, 72)
[42] (Ramlow, Foster, Del Grosso, & Cotrufo, 2019, p. 78)
[43] (Ramlow & Cotrufo, 2017, p. 2)
[44] (Ramlow & Cotrufo, 2017, p. 1)
[45] (Ramlow, Foster, Del Grosso, & Cotrufo, 2019, p. 72)
[46] (Koper, et al., 2010, p. 4)
[47] (Ramlow, Foster, Del Grosso, & Cotrufo, 2019, p. 72)
[48] (Galinato, Suzette P.; Yoder, Jonathan K.; Granatstein, David, 2011, pp. 2, Table 1)
[49] (Manning, 2017)
[50] (Ramlow & Cotrufo, 2017, p. 12)
[51] (Ramlow, Foster, Del Grosso, & Cotrufo, 2019, p. 72)

- **Reduces non-point source pollution** – In the Chesapeake Bay, biochar-filled bioreactors are used to filter nutrients and improve water quality.[52]

These are but a few of biochar's applications but some of the better-known ones. As biochar gains public awareness, more studies are emerging in real-time showing additional benefits and uses for the material.

Manufacturing Biochar – There are a number of ways to manufacture biochar, and all involve pyrolysis. *Pyrolysis* is the oxygen-free or low-oxygen thermochemical process that converts woody biomass into a carbon-rich residue (biochar), gases (syngas), and condensable vapors, with no reagents except possibly steam.[53] See Table 2 for some pyrolysis processes.

Table 2 – Various Pyrolysis Processes, Properties & Outputs

PROCESS	TEMPERATURE	HEATING RATE	RESIDENCE TIME	BY-PRODUCTS (%) Biochar	Bio-Oil	Syngas
Fast pyrolysis	400 - 1,000 °C	Very fast (appx 1,000 °C/s)	<2 s	12	75	13
Slow pyrolysis	350 - 980 °C	Slow (<10 °C/min)	1 hr	27 - 37	19 - 29	25 - 41
Hydrothermal carbonization (HTC)	180 - 300 °C	Slow	1-16 h	50 - 80	5 - 20	2 - 5
Gasification	700 - 1,500 °C	Moderate - very fast	10 - 20s	10	5	85
Torrefaction	200 - 300 °C	Slow (<10 °C/min)	appx 10 - 60 min.	80	0	20

(Enaime, Baçaoui, Yaacoubi, & Lübken, 2020, p. 3)

Variations in pyrolysis include temperature and residence time, which can render different percentages of solid, liquid, and gaseous output.[54] James Gaspard at Biochar Now uses a *slow pyrolysis* process, heating feedstock for 8 to 10 hours between 400 and 650°C (752 to 1,202°F).[55] For purposes of this plan, the Consultant assumes the Company uses Biochar Now's system. The consultant has, however, spoken to (and continues to speak to) a number of biochar producers using various processes. Exploration of these other pyrolizers and systems should happen routinely as the types have different outputs, labor needs, electric and fuel use, and other expenses. (See Appendix A for timeline.)

[52] (eXtension, 2019)
[53] (Koper, et al., 2010, p. 9)
[54] (Hagemann, et al., 2018, p. 7)
[55] (James Gaspard, personal communication, May 28, 2020)

Figure 3 - Looking to Bridge Biochar's Big Information Gap

(Moor, 2018)

Biochar's (*BIG*) Information Gap (BIG)

While biochar was used by prehistoric farmers, it has experienced a resurgence since 2010, especially in agriculture.[56] The European Biochar Certificate certification says that there has been significant uptake since 2015 and to expect further acceleration from 2020 on.[57] Launched in 2014, Project Drawdown popularized biochar as a tool capable of sequestering between 2.22 and 4.39 gigatons of carbon between 2020 and 2050.[58] The Consultant, too, has noticed a rise in research and peer-reviewed papers since approximately 2015, a number coming from China.

Figure 4 - Cool Planet's coolterra Biochar

(www.CoolTerra.com, 2018)

The Consultant has also identified a *big* biochar information gap among the approximately two dozen interviewees with whom she spoke: professional engineers, scientists, stormwater and wastewater professionals, and

56 (Schmidt, et al., 2020, p. 7)
57 (Schmidt, et al., 2020, p. 7)
58 (Project Drawdown, 2020)

filtration manufacturers. Some had heard of biochar, some had not, some had had biochar salespeople knocking on their doors, yet not one had a clue about how to use it to solve their filtration problems. Not one.

One example posted here is coolterra, a biochar mix previously produced by Cool Planet (see Figure 4 and "The Competition" section for Cool Planet). While the name is … cool, it does not say anything about what it is. Cool Planet failed to bridge the BIG.

This BIG information gap is a hurdle to leap and something the Company must address.

Biochar Certifications & "Clean Urban Wood"

The Consultant cannot impress upon the Company enough the importance and gravity of using only clean urban wood in biochar production. *Metro Biochar® and any other biochar products the Company makes will literally be under the microscope in applications like water and effluent treatments. There are some certifications that can help achieve quality assurance.*

Figure 5 - USDA BioPreferred

(USDA United States Department of Agriculture, n.d.)

External, Third-Party Certifications – Three certifications can help verify and vet Metro Biochar®, providing assurance to customers.

USDA BioPreferred – This U.S. Department of Agriculture certification says that products are "derived from plants and other renewable agricultural, marine, and forestry materials and provide an alternative to conventional petroleum derived products. Bio-based products include diverse categories such as lubricants, cleaning products, inks, fertilizers, and bioplastics."[59] Since the certification limns bio-based products, that means burning MSW, sewage sludge (into biosolids), etc., is forbidden.[60] The certification also does not certify food, animal feed, or fuel.[61] On the upside, the certification includes mandatory purchasing for federal government agencies and contractors, and grants toward the certification are also available.[62]

---

[59] (USDA United States Department of Agriculture, n.d.)
[60] (USDA United States Department of Agriculture, n.d.)
[61] (USDA United States Department of Agriculture, n.d.)
[62] (USDA United States Department of Agriculture, n.d.)

IBI Certification – The International Biochar Initiative provides a certification with "stipulations of maximum concentrations for potentially toxic chemicals and compounds."[63] Certified biochars must not include more than two percent (dry weight) from a lengthy list of contaminants, and the certification does not apply to product blends or mixes, sustainability, or greenhouse gas calculations.[64]

Figure 6 - IBI Certified Biochar Logo

(International Biochar Initiative, 2018)

OMRI – "OMRI is a 501(c)(3) nonprofit organization that provides an independent review of products, such as fertilizers, pest controls, livestock health care products, and numerous other inputs that are intended for use in certified organic production and processing."[65] Anyone growing or processing organic products looks for the OMRI certification to verify that inputs align with final organic certification.[66]

Figure 7 - OMRI Logo

(OMRI, 2020)

Recommendations for Certifications – The Consultant recommends that the Company certify Metro Biochar® with the USDA BioPreferred and IBI Certification labels. If it becomes appropriate in the future to pursue OMRI, the Company can explore that at that time. The Consultant has also added the certifications in "The Competition" section showing what the Company's competitors are doing.

Additionally, it is imperative that the Company create an internal certification and failsafe vetting process for treated wood. The Company must educate workers to spot and/or test for treated wood and other contaminant sources, and this needs to be broadcast via training, banners, and any other means to keep it foremost in workers' minds. The Company may (*may)* get one do-over on this, but if production of contaminated wood is habitual, customers will flee.

---

63 (International Biochar Initiative, 2018)
64 (International Biochar Initiative, 2018)
65 (OMRI, 2020)
66 (OMRI, 2020)

Market Size & Target Markets

In 2018, the U.S. Forest Service produced a study surveying the U.S. biochar industry with a 45 percent response rate from producers and users.[67] (See Appendix B for entire report.) The results are highlighted here.

- **Annual production** – The industry survey supports industry sales of 35,000 to 70,000 tons per year (TPY).[68]
- **Biochar price** – Prices range broadly in the survey, from $75 per cubic yard ($600 per ton, assuming 8 cubic yards per ton) to $200 per cubic yard (FOB, $1,600 per ton).[69] Biochar Now claims to sell product at $2,000 per ton, an outlier price. A paper written in 2011 shows another Colorado producer pricing at $2.20 per kilogram (also $2,000 per ton).[70] *Notably this was not necessarily a profitable price for this producer when labor underperformed and productivity measures were down*.[71]
- **Industry cap** – Table 3 shows a number of estimates for biochar industry market capitalization based on the data provided in the industry survey. Depending on the TPY and price per ton modeled, industry capitalization ranges from $10,500,000 (at 35,000 TPY and $300 per ton) to $112,000,000 (at 70,000 TPY and $1,600 per ton). Mid-range estimates for TPY (52,500) and both $500 and $600 price per ton show a market cap of between $26,250,000 and $31,500,000. From the Consultant's research, this range is conservative and defensible.

Table 3 - Estimations of Industry Capitalization Based on Biochar Industry Survey

TONS BIOCHAR PRODUCED PER YEAR (TPY)	LOW PRICE $300/Ton	MED PRICE $500/Ton	MED PRICE $600/Ton	HIGH PRICE $1,600/Ton
35,000	$ 10,500,000	$ 17,500,000	$ 21,000,000	$ 56,000,000
52,500	$ 15,750,000	***$ 26,250,000***	***$ 31,500,000***	$ 84,000,000
70,000	$ 21,000,000	$ 35,000,000	$ 42,000,000	$112,000,000

(U.S. Forest Service, 2018)

67 (U.S. Forest Service, 2018, p. 6)
68 (U.S. Forest Service, 2018, p. 2)
69 (U.S. Forest Service, 2018, p. 6)
70 (Kim, Anderson, & Chung, 2015, p. 192)
71 (Kim, Anderson, & Chung, 2015)

- **Market growth** – Both global and domestic markets for biochar are growing, and not one of the respondents expects a decline in the market.[72] In fact, 60 percent expect market demand to increase 10 percent.[73] In Colorado, a 2017 article in *coloradobiz* stated that the industry was worth $1.5 million, and that it has been *doubling year to year*.[74] By that calculation, the industry cap in Colorado should be $12 million in 2020, though business impacts for COVID are not figured here.

Globally, another industry report says the North American market and consumer have the greatest awareness of biochar and, as a result, the U.S. market is the largest.[75] The global market is worth $1.3 billion with demand estimated at 395.3 kilotonnes (435,778 U.S. tons, 2018).[76] The global market is growing at 13.8 percent CAGR (compound annual growth rate).[77] Environmental awareness, cheaper cost of feedstock, and cohesive government policies are needed to keep this growth rate up.[78]

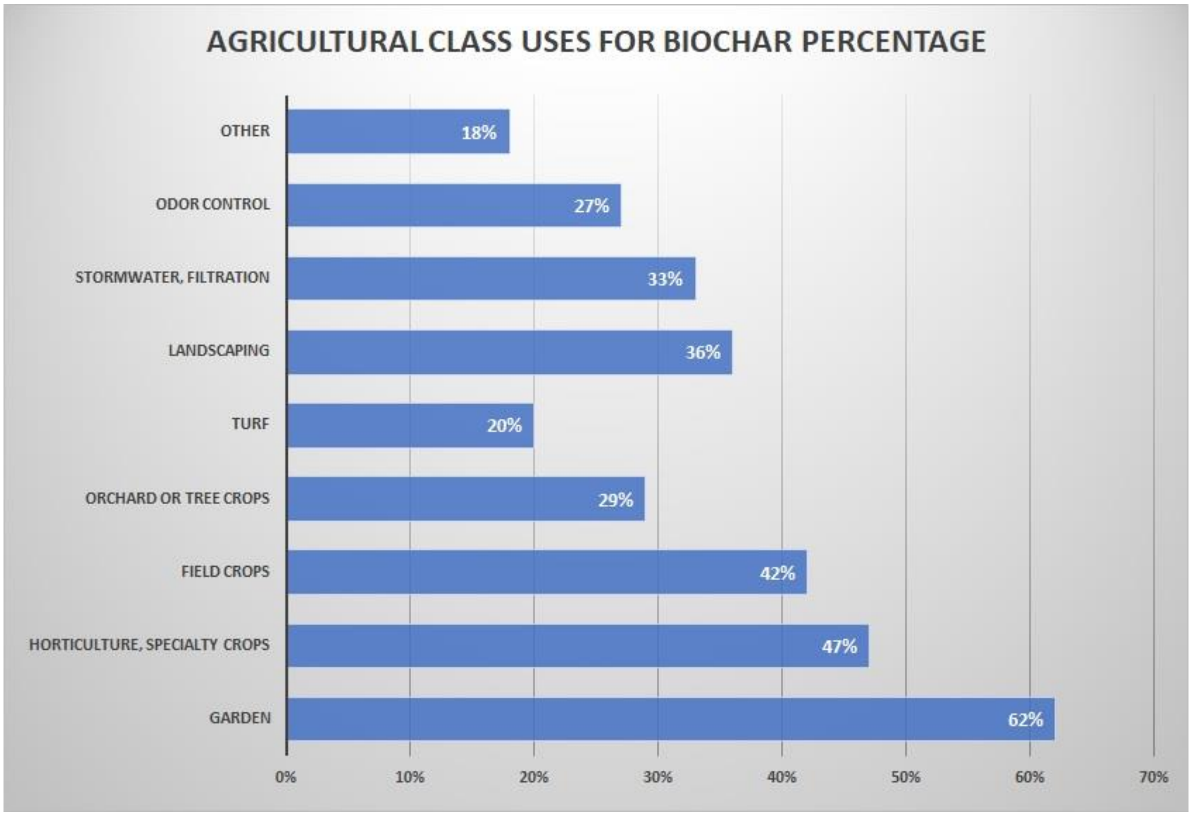
The global market consists of a few large-scale producers and a growing number of small and midsize producers.[79] Pyrolysis is considered the most efficient production process while gasification does not produce stable biochar.[80] Biochar for water treatment is expected to be another important future application because of the need for water-treatment plants, especially in the developing world (China, India).[81]

- **Feedstock inputs** – Assuming a 25 percent pyrolysis conversion rate, the industry requires 200,000 *dry* tons of biomass feedstock annually.[82]

Market Segments – Most producers sell biochar for agricultural uses, including horticulture and specialty crops (47 percent), field crops (42), turf (20), landscaping (36), stormwater and filtration (33), and odor control (27).[83] (See Figure 8.)

[72] (U.S. Forest Service, 2018, p. 4)
[73] (U.S. Forest Service, 2018, p. 4)
[74] (Romig, 2017)
[75] (Grand View Research, Inc., 2019)
[76] (Grand View Research, Inc., 2019)
[77] (Grand View Research, Inc., 2019)
[78] (Grand View Research, Inc., 2019)
[79] (Grand View Research, Inc., 2019)
[80] (Grand View Research, Inc., 2019)
[81] (Grand View Research, Inc., 2019)
[82] (U.S. Forest Service, 2018, p. 2)
[83] (U.S. Forest Service, 2018, pp. 3-4)

Figure 8 - Agricultural Class Uses for Biochar Percentage



(U.S. Forest Service, 2018, pp. 3-4)

- **Distribution** – The majority of biochar is produced and sold within 500 miles, supporting a *regional* production and distribution model.[84]
- **Carbon sequestration** – Almost 25 percent of respondents mentioned carbon negativity (sequestration) as well as the need to financially benefit from it.[85] This recognition was cited as having *the* greatest potential to drive up demand, though more scientific results and policy levers were cited as necessary.[86]

A few of the larger scale producers and carbonizer manufacturers are: Airex Energy Inc., Diacarbon Energy Inc., 3R Environmental Technologies, Ltd., Phoenix Energy, and Pacific Pyrolysis Pty Limited.[87]

---

[84] (U.S. Forest Service, 2018, p. 4)
[85] (U.S. Forest Service, 2018, p. 7)
[86] (U.S. Forest Service, 2018, p. 7)
[87] (Grand View Research, Inc., 2019)

Market Segmentation

Figures 8 and 9 show some of the bigger sectors for biochar use, and the Consultant surveys the larger ones here, including current recommendations for the Company's biochar sales in Colorado.

Agriculture, Lower- & High-Value Crops – Colorado State University (CSU) Professor and soils scientist M. Francesca Cotrufo, along with others, have studied the impact of biochar on crops, especially maize and wheat on Colorado's eastern plains.[88] The results have been promising: Biochar helps soils retain water.[89] Biochar sequesters carbon and N_2O runoff.[90] And in other places, some similar to Colorado, biochar boosts crop yields depending on crops and soil types.[91]

One 2011 study, however, demonstrates that winter wheat grown in western Washington state does not create a profitable business case without carbon payments of $31 or more per metric tonne of CO_2.[92] Additionally, the Western Slope of Colorado supports growth of Palisade peaches, grapes, and other high-value crops.[93,94] CSU Professor and Western Colorado Research Center Manager Greg Litus says one acre of Western Slope peaches can produce $10,000 in revenue for a farmer.[95] Yet after running experiments with biochar on peach plots, he says he found no significant differences in crop yields due to what he says are the high cation exchanges in biochar and the highly alkaline soil in western Colorado.[96]

Agriculture, Retail Sales – The Consultant performed an Internet pricing search in April 2020 on a dozen available retail biochar units (see Table 4). None were created in Colorado, and most came from well over 1,000 miles away, requiring expensive transportation. Prices approximate $35 per gallon or $25 per pound. Most units were sold in either 1 cubic-foot bags at around $30 per bag or 5-gallon buckets at $150 to $175 per bucket. *Also important to note is that several biochar products contain compost so pricing biochar for retail sale also must identify whether it is a mixed product or not.*

---

[88] (Ramlow & Cotrufo, 2017)
[89] (Ramlow, Foster, Del Grosso, & Cotrufo, 2019, p. 71)
[90] (Ramlow & Cotrufo, 2017, p. 1)
[91] (Galinato, Suzette P.; Yoder, Jonathan K.; Granatstein, David, 2011, pp. 6345, Table 1)
[92] (Galinato, Suzette P.; Yoder, Jonathan K.; Granatstein, David, 2011, pp. 6348, Table 3)
[93] (Miller, 2014)
[94] (Greg Litus, Ph.D., personal communication, July 20, 2020)
[95] (Greg Litus, Ph.D., personal communication, July 20, 2020)
[96] (Greg Litus, Ph.D., personal communication, July 20, 2020)

Agriculture, Animal Feed – The Consultant did not explore in depth using biochar as an animal feed supplement for a couple of reasons: (1) it's not currently allowed by the U.S. Department of Agriculture (USDA), and (2) this current prohibition is cited by 26 percent of large biochar producers as a market impediment.[97,98]

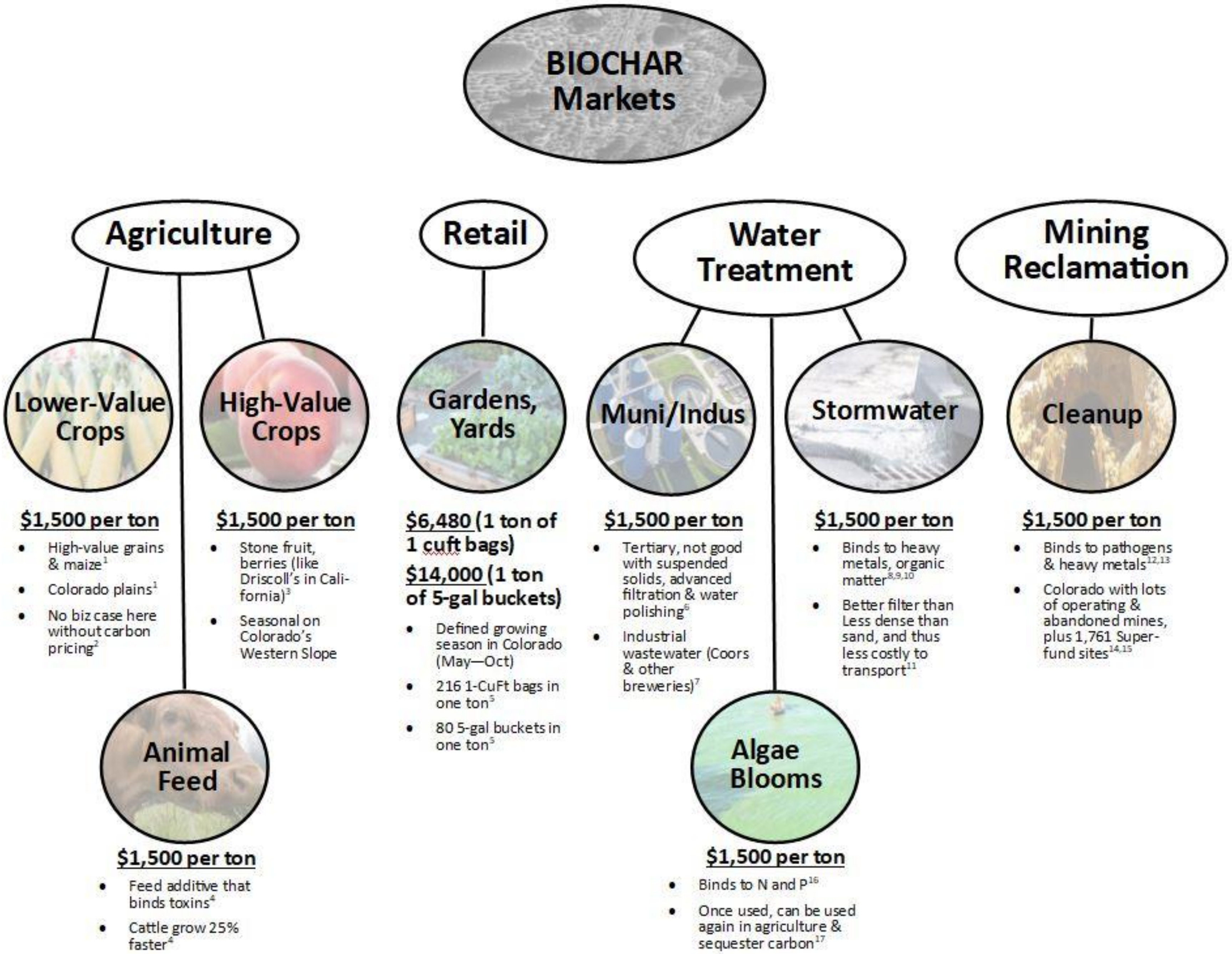
Recommendations for Agricultural Sector Sales (see Figure 10) – For large-scale agriculture, the Consultant recommends that the Company forego this sales avenue for now until some form of carbon pricing is in place. The Consultant also recommends updating the Washington state wheat/carbon model to find the breakeven price for carbon, wheat, and maize profitability in eastern Colorado. When some form of carbon pricing is in place, the Company should revisit this as a sales channel. The Consultant is also exploring use of biochar for *Cannabis*, most assuredly a high-value crop at $300 per pound.[99]

The high sales price of retail biochar merits further investigation in either Phase II or Phase III (years one and two of sales). This should happen after biochar sales proof of concept is successful. The Consultant also advises that using biochar as an animal-feed supplement is shelved for now. The Company should keep vigilance on this subject as USDA approval may open a future market regionally.

---

[97] (U.S. Forest Service, 2018, p. 1)
[98] (James Gaspard, personal communication, May 28, 2020)
[99] (Yonos Coleman, personal communication, 2017)

Figure 9 - Biochar Market Segments, Prices & Uses



(Cont.) Biochar Market Segments, Prices & Uses (citations)

1 (Ramlow, Foster, Del Grosso & Cotrufo, 2019, p. 71)
2 (Galinato, Suzette P.; Yoder, Jonathan K.; Granatstein, David, 2011, p. 6348, Tables 1, 2)
3 (Greg Litus, Ph.D., personal communication, July 20, 2020)
4 (James Gaspard, personal communication, May 28, 2020)
5 See Table 4
6 (Huggins, Haeger, Biffinger & Ren, 2016, p. 3)
7 (Huggins, et al.)
8 (Enaime, Baçaoui, Yaacoubi, & Lübken, 2020, pp. 1, 8)
9 (Huggins, Haeger, Biffinger & Ren, 2016, p. 3)
10 (Perez-Mercado, Lalander, Berger, & Dalahmeh, 2018), pp. 1, 16)
11 (Perez-Mercado, et al., 2018), pp. 1, 16)
12 (Enaime, Baçaoui, Yaacoubi, & Lübken, 2020, pp. 1, 15)
13 (Enaime, et al., pp. 1, 8)
14 (U.S. Department of the Interior, n.d.)
15 (EPA United States Environmental Protection Agency, 2020)
16 (Perez-Mercado, Lalander, Berger, & Dalahmeh, 2018, pp. 2, 16)
17 (James Gaspard, personal communication, May 28, 2020)

Microscopic view biochar (Pranitha, 2017); Olathe corn, Colorado peaches & cow eating (Miller, 2014); Raised growing beds (DeannaCat, 2020); Wastewater treatment (Pepper+Fuchs, 2020); Stormwater (The Town of Amherst, n.d.); Abandoned mine (Lotus, 2020); Algae bloom in Baltic Sea (esa, 2020)

Table 4 – Online Retail Biochar Pricing Survey Done April 2020

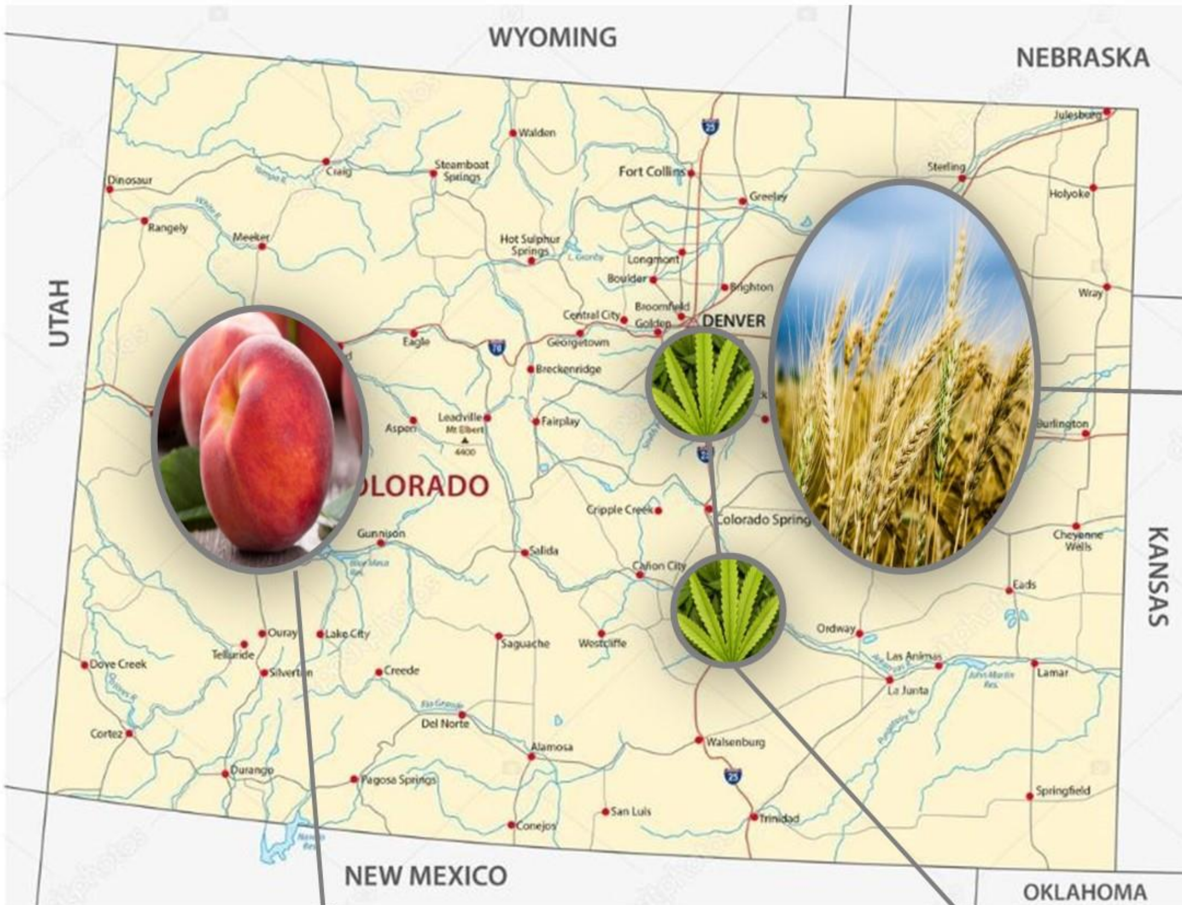
BIOCHAR MARKETS - Retail & Agricultural

PRODUCT	MANUFACTURER/MAKER	LINK	MILES FROM DENVER	CODE	CERTS?	BLEND?	UNIT (Weight lbs)	UNIT (Cu.Ft.)	UNIT (gals)	TOTAL RETAIL PRICE ($)	RETAIL PRICE PER lb	RETAIL PRICE PER UNIT (Cu.Ft.)	RETAIL PRICE PER UNIT (gal)	NOTES
BioChar Source	CharGrow	https://rb.gy/3buwlb	1,449	Ag		YES								100% bio-***BLEND*** organic compost, worm castings, minerals and fungi. Ag supplier that bids to spec.
BioCharPlus	Charcoal Green (@eBay)	https://rb.gy/auuakv	273	Retail		NO	*25.00*		5.00	187.99	$ 7.52		$ 37.60	Charcoal Green, the vendor, sells for $157.99 ***with free local pickup. Shipping costs $30.***
Biochar organic soil amendment	MidwestBiochar (@ Etsy)	https://rb.gy/ekzt4a	604	Retail		NO	*25.00*		5.00	$ 175.00	$ 7.00		$ 35.00	On Etsy. $35 per gallon with no volume discounts.
Biochar Soil Conditioner	Wakefield	https://rb.gy/itchkq	729	Retail	USDA	NO	25.00	1.00		$ 29.99	$ 1.20	$ 29.99		Pure biochar. They have a "nutritional" label on the front showing what's in it.
Biochar	Biochar pure (@ eBay)	https://rb.gy/wrkmxb	1,140	Retail		NO	40.00			32.00	$ 0.80			Biomerchants, the vendor, sells for $32 ***with free local pickup***. So shipping not included. Packaging nothing special.
Biochar	Aries Green (@ Home Depot)	https://rb.gy/ivc1nv	1,178	Retail	USDA & IBI	NO	*25.00*	0.67	5.00	$ 74.95	$ 3.00		$ 14.99	5-gallon bucket of 100% biochar. ***Made responsibly from waste wood from a downdraft gasification system. 96% C. Cubic footage is suspect, and there are other comments on Home Depot's website that agree.*** I can't find other data.
Premium Organic Biochar	Concentrates Inc.	https://rb.gy/cq2zx9	1,248	Retail	OMRI	NO		1		$ 31.00		$ 31.00		OMRI - Organic Materials Review Institute. OMRI-listed productts are allowed in certified organic operations under the USDA National Organic program.
Biochar	Lewis Bamboo	https://rb.gy/isn0od	1,262	Retail		NO	10.00		1.25	49.99	$ 5.00		$ 39.99	This product is originally $49.99, marked down to $29.99, which would be 23.99 per gallon. I went with the retail price.
Premium Biochar	Mother Earth	https://rb.gy/i76gdn		Retail		NO		1.00		$ 43.99		$ 43.99		Marked down on another website to $26.66.
Biochar Blend	GreenGro Earth Shine	https://rb.gy/f7nbgn	1,270	Retail		YES	30.00		5.00	$ 150.00	$ 5.00		$ 30.00	***BLENDED*** with worm castings and humic acid.
Biochar blend	Organic Mechanics (@ terrain)	https://rb.gy/oxlnaa	1,690	Retail		YES		1.00		$ 30.00		$ 30.00		***BLEND*** with 50/50 biochar and "top-blended organic ingredients (worm castings, compost, alfafa & kelp meal, bone char, zeolite & azomite).
BIOCHAR Blended with all natural fertilizer	Vermont Organics Reclamation (@ Home Depot)	http://tiny.cc/tx7mnz	1,930	Retail		YES	12.00	1.00		$ 29.95	$ 2.50	$ 29.95		This is a ***BLEND*** of 3 pounds biochar with 9 pounds of coffee skins. If it were just 3 lbs biochar, price = $9.98.

** Wakefield BioChar: 1 Cu/ft bag = covers appx. 375 SF. 1 gal bag = appx. 55 SF.*

*** Charcoal Green: 5 gal = appx. 25 lbs*

Figure 10 - Three Agricultural Zones in Colorado



EASTERN PLAINS

- Lower-value crops ($150/acre for corn)[6]
- Alkaline soils[7]
- Biochar assumed to work better with smaller plants[8]

WESTERN SLOPE

- High-value crops ($10,000 per acre for peaches)[1]
- Alkaline soils[2]
- Early studies show no significant gains in crops yields with biochar[3]
- Biochar assumed to work better with smaller plants[4]

CANNABIS HUBS—DENVER & PUEBLO

- High-value crops ($300 per pound)[5]
- Carefully controlled 24/7 grow houses
- Biochar a possible soil amendment and crop booster

1,2,3,4,6,7,8 (Greg Litus, personal communication, July 20, 2020)
5 (Yonos Coleman, personal communication, 2017)

Municipal & Industrial Wastewater Treatment – Biochar is a good alternative for treating water and wastewater as it binds to heavy metals[100], organic matter[101,102,103], pathogens[104], nitrogen, and phosphorus.[105] Additionally, biochar outperforms sand as a filtration medium, is less dense than sand, and thus less costly to transport.[106]

The Consultant had phone calls with half a dozen municipal wastewater engineers this summer. While most were open to the idea of a less-costly filtration medium, it became clear the end customer for biochar is farther up the supply chain – *filtration manufacturers*. A couple of wastewater treatment experts interviewed suggested several companies to approach about biochar bench studies, especially comparing it to granular activated carbon (GAC): *Amiad (N. Car.), WesTech Engineering, Inc. (Utah), Pure Aqua, Inc. (Cali.)*, and *engineers GSI Environmental (Houston)*.[107] Another study compared biochar and activated charcoal in *industrial* wastewater at Coors Brewery with promising results.[108] The Consultant has reached out to both the Chief Sustainability Head and another process engineer at Molson-Coors but has not gotten a response.

Recommendations for Industrial and Municipal Wastewater – *The price of GAC is approximately $8,000 per ton whereas biochar is up to $2,000 per ton* (see Table 4 and Figure 9).[109] *While a number of papers demonstrate biochar's effectiveness in treating wastewater, bench studies are needed to produce technical and use specifications (TUS) and possibly replacement of GAC (in whole or part) with biochar*. If biochar can function as effectively as GAC or even close, this is reason enough to pursue this sales avenue. The Consultant recommends finding study participants in Phase 1 and beyond to create technical specifications for biochar usage, especially as a replacement for GAC in wastewater treatment.

Stormwater Treatment – Of all the biochar markets explored, treating stormwater is the most promising to date. The Consultant sent out 13 emails on July 16, 2020 and within 24 hours, heard back from five people, with more mentioned within email texts. The Consultant has since had phone calls with approximately a dozen stormwater engineers and experts. All know of biochar,

---

[100] (Enaime, Baçaoui, Yaacoubi, & Lübken, 2020, pp. 1, 8, 15)
[101] (Enaime, Baçaoui, Yaacoubi, & Lübken, 2020, pp. 1, 8)
[102] (Huggins, Haeger, Biffinger, & Ren, 2016, p. 3)
[103] (Perez-Mercado, Lalander, Berger, & Dalahmeh, 2018, pp. 1, 16)
[104] (Enaime, Baçaoui, Yaacoubi, & Lübken, 2020, pp. 1, 15)
[105] (Perez-Mercado, Lalander, Berger, & Dalahmeh, 2018, pp. 2, 16)
[106] (Perez-Mercado, Lalander, Berger, & Dalahmeh, 2018, pp. 1, 16)
[107] (Chaney Phillips, personal communication, July 9, 2020)
[108] (Huggins, Haeger, Biffinger, & Ren, 2016, p. 2)
[109] (Chaney Phillips, personal communication, July 9, 2020)

and one described it as "the next boom."[110] Two practitioners suggested that the missing link for using biochar is TUS.[111]

Almost all experts spoken with said the top three pollutants they must deal with are *E. coli*, *nitrogen (N)*, and *phosphorus (P)*, though others were mentioned like heavy metals and nutrients. Legacy treatments for E. coli include ultraviolet (UV) light, but a stormwater engineer for the City and County of Denver says UV is a costly and labor-intensive way to treat wastewater.[112]

The Mile High Flood District (MHFD) is an overarching entity that provides services to 41 government entities in the Denver metro region, including the City and County of Denver.[113] Several experts suggested that if biochar TUS were included in the *Urban Storm Drainage Criteria Manual: Volume 3*, it would be much easier for them to incorporate biochar into stormwater treatment.[114] Known as *Volume 3*, the 577-page document provides best practices for stormwater treatment.[115]

The Consultant spoke with Holly Piza, a Professional Engineer, the Standards Development Manager of MHFD, and co-author of *Volume 3*.[116] Ms. Piza encouraged the Consultant and the Company to stay in touch about biochar research to help tailor it to the needs of MHFD constituents.[117] *Volume 3* is also being updated this fall, and Ms. Piza invited the Consultant to participate in that process.[118]

Recommendations for Stormwater Treatment – The Consultant recommends this area as a top priority and focus because of practitioner recognition of biochar and access granted by stakeholders. The Company should move forward *immediately* in Phase 1 to work with MHFD and other third-party organizations, including educational institutions like Colorado School of Mines. *The goal is to create TUS for biochar use in treating stormwater, landfill leachate, and other water bodies, and in having these specs added into Volume 3 as soon as possible.*

---

[110] (Juliana Archuleta, personal communication, July 27, 2020)
[111] (Juliana Archuleta & Heather Otterstetter, personal communication, July 27, 2020)
[112] (Darren Mollendor, personal communication, July 30, 2020)
[113] (Mile High Flood District, 2020)
[114] (Juliana Archuleta & Heather Otterstetter, personal communication, July 27, 2020)
[115] (Urban Drainage and Flood Control District, 2010)
[116] (Mile High Flood District, 2020)
[117] (Holly Piza, personal communication, Aug. 12, 2020)
[118] (Holly Piza, personal communication, Aug. 12, 2020)

Mining Reclamation – The U.S. Biochar Industry study says that while stormwater filtration, odor control, and mine reclamation are currently small segments of the market, they have "large potential."[119] In addition to its other capabilities, biochar shows "promising results" in treating landfill leachates, and it removes metals (Cd, Hg, Ni, Mn, Cu, Zn, Pb).[120]

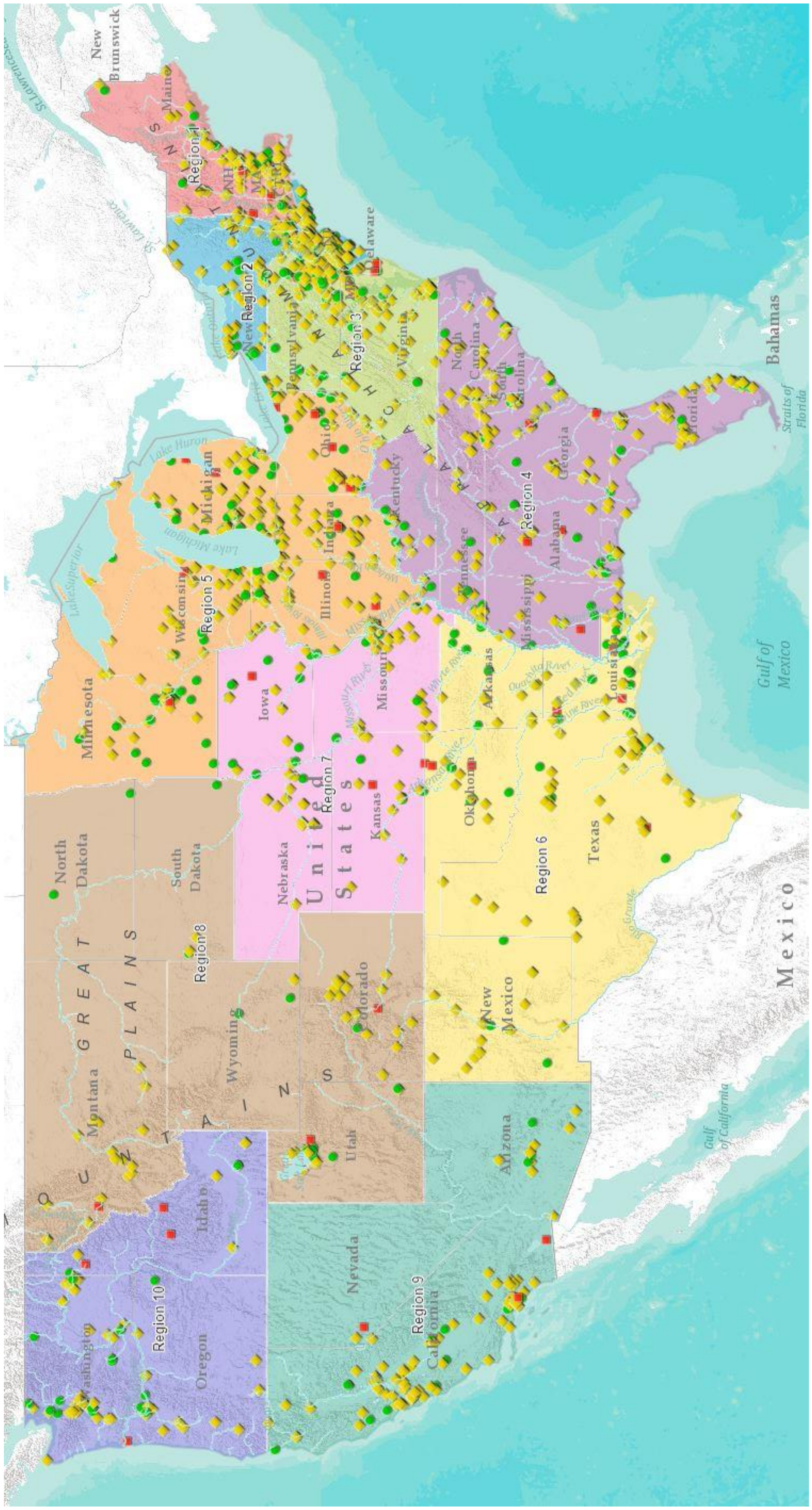
Colorado is an ideal place to target mine cleanups. The state has 17,661 mining sites, placing second behind only California with 42,749 sites.[121] Also, the state has a number of listed Superfund sites (see Figure 11).[122]

Recommendations for Mine Reclamation *– Mine reclamation and cleanup should be the second sales sector targeted because of the number of mines and Superfund sites in Colorado and the competitiveness of biochar's price to activated carbon's.* While the Consultant did not do a deep dive in this segment, the Company should explore potential clients and mine owners in Phase 1. Also, parallel work on developing TUS for mine reclamation should continue with mine waste and contaminants included also. This will provide much-needed empirical data for customers in both spheres with as few research pushes as possible.

---

[119] (U.S. Forest Service, 2018, p. 1)
[120] (Gunarathne, et al., 2018, pp. 236-7)
[121] (U.S. Department of the Interior, n.d.)
[122] (EPA United States Environmental Protection Agency, 2020)

Figure 11 - EPA Superfund Sites Across The Lower 48 United States



(EPA United States Environmental Protection Agency, 2020)

The Competition

The Competition – See Appendix C (i-viii) for SWOT analyses and Figure 12 for competitor map.

Biochar Now (Berthoud, Colo.) – Biochar Now is the largest biochar producer in Colorado, and owner James Gaspard is well-known if not necessarily well-liked.[123] He prices his biochar high ($2,000 per ton) and has varied sales sectors: high-value crops soil amendment in California, plastics additives, and algae bloom mitigation.[124]

Mr. Gaspard uses forest slash to create biochar but complains of supply constraints with his woody biomass feedstocks, some coming from as far as Oregon. He says his breakeven price is $0.30 per pound ($600 per ton) and he makes profit at $0.40 per pound ($800 per ton).[125] He seems to have neither the appetite nor the capability to provide TUS and thus, create new water-treatment sales channels. He also mentions that he provides documentation for his clients who sell carbon dioxide removal certificates ("CORCS") on the Finnish trading platform Puro.earth.[126] Yet the technical documents upon which Puro relies *expressly forbid biochar pyrolysis fired by fossil fuels*.[127] Either Mr. Gaspard is unaware of this, or he is misrepresenting his processes.

CERTS: OMRI, USDA BioBased Product[128]

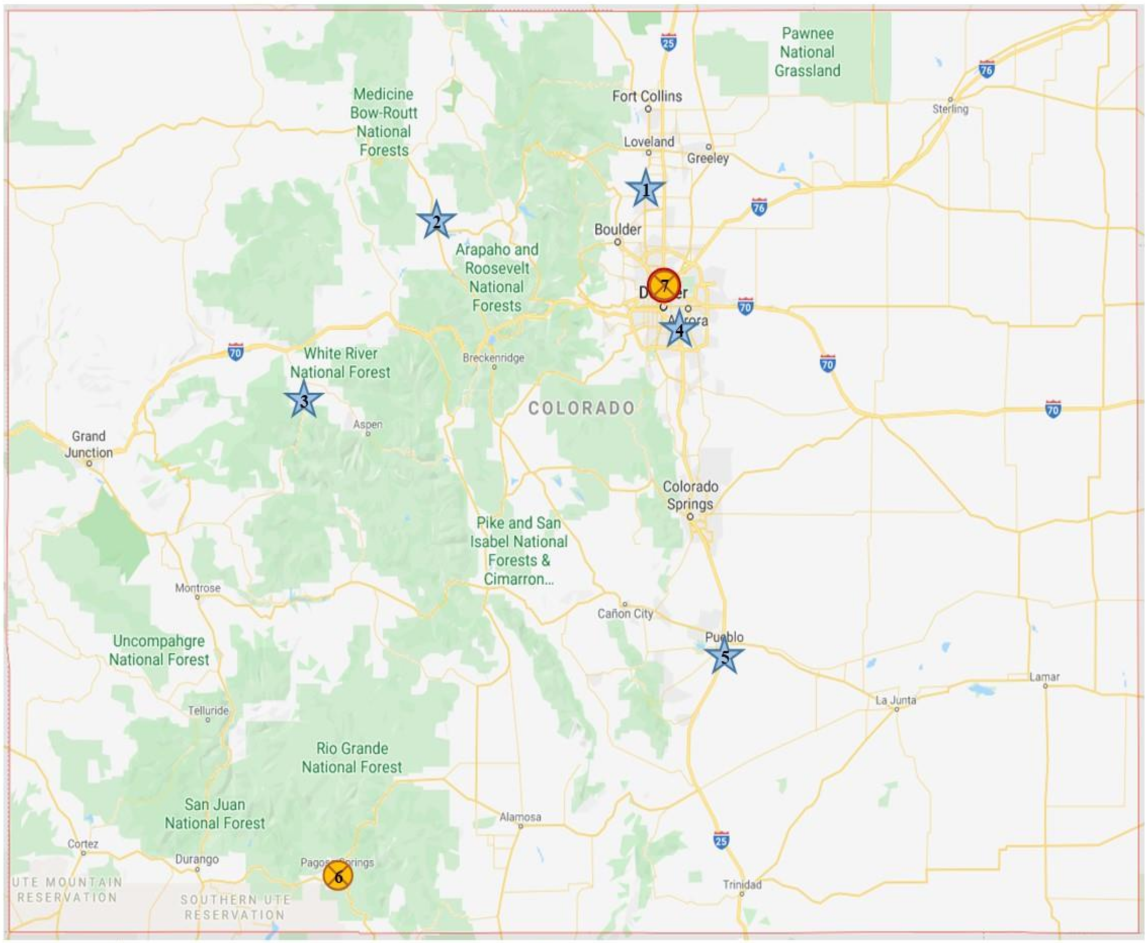
Confluence Energy (Walden and Kremmling, Colo.) – Confluence Energy initially sold wood pellets for heating, but low oil and gas prices threw the company into bankruptcy in 2018, with final company sale in 2019.[129,130] Confluence now offers a nicely branded range of filtration products, soil amendments, and biochar targeted to the mountain and agricultural communities.[131] Jonah Levine, a long-time biochar producer, is now a sales rep for the company.[132] A colleague of the Consultant has reached out to Mr. Levine several times for reconnaissance on his pricing, but he has not returned a call.

---

[123] (Ron Larson, personal communication, July 13, 2020)
[124] (James Gaspard, personal communication, May 28, 2020)
[125] (James Gaspard, personal communication, July 16, 2020)
[126] James Gaspard, personal communication, May 28, 2020)
[127] (Schmidt, et al., 2020, p. 22)
[128] (Biochar Now, n.d.)
[129] (Gounley, 2018)
[130] (BBI International, 2019)
[131] (confluence energy, 2020)
[132] (confluence energy, 2020)

Figure 12 - Biochar Providers & Operations Across Colorado

Colorado Biochar-Producing Companies—Existing and In Development



Legend. ★ Represents existing biochar operations. ⊗ Represents operations that are either in Colorado Department of Public Health and Environment permitting or in development.

(Google, 2020) (COLORADO Department of Public Health & Environment, 2019)(Colorado Secretary of State, 2020)

1. **Biochar Now (2011)**
   Berthoud, CO
   James Gaspard

2. **Confluence Energy (2007)**
   Kremmling & Walden, CO
   Mark Mathis

3. **Biochar Solutions (2011)**
   Carbondale, CO
   Jonah Levine

4. **Cool Planet Energy Systems (National Carbon Technologies, 2013)**
   Greenwood Village, CO

5. **Colorado Biochar Resources (2011)**
   Pueblo, CO
   Micah Langston

6. **Pagosa Forest Products, LLC (2018)**
   Pagosa Springs, CO
   James R. Ford

7. **5280 Recycling Solutions, LLC (2017)**
   Denver, CO
   Bill Bradley

Confluence has two manufactories in Colorado: Walden and Kremmling.[133] Confluence targets heavy industrial users like oil and gas, water filtration, and mining reclamation, yet the company does not have products listed.[134] Confluence targets the same heavy industrial users that the Company intends, but they are located nowhere near Denver. Nor presumably are their buyers.

CERTS: "Organic," Colorado Proud[135]

Biochar Solutions (Carbondale, Colo.) – Biochar Solutions (BS|C) is (also) owned by Jonah Levine, sales rep for Confluence Energy. BS|C's advantage is what Levine describes as a distributed network of biochar providers.[136] He creates biochar, consults, and sells equipment.[137] He is also presumably the equipment provider for the reconstituted Confluence Energy.

BS|C is in a remote location (173 miles to Denver and 382 to Salt Lake City). If he chose to go into C&D biochar production, he would undoubtedly do well because of his industry knowledge. Yet he is in a remote location without the concentration of C&D waste to fill his biochar kilns.

Cool Planet (Greenwood Village, Colo.) – Cool Planet (CP) is the sleeping giant in Colorado, located just south of Denver in Greenwood Village. Initially a green-tech startup funded by Google, BP, GE and Conoco Phillips, the company advertised "cheap fuel that reverses global warming."[138] As such, CP was using gasifying technology to create fuel with biochar as a secondary product, though its environmental claims were questioned.[139]

CP was bought by National Carbon Technologies (NCT) in June 2020, which has ambitions to be the global leader in biochar production.[140] NCT's current headquarters is in Marquette, Mich., with a new production facility in Louisiana set to open in fourth quarter 2020 (Q4) and with production capacity of 25,000 tonnes of biochar annually.[141,142]

The coolterra name does not bridge the *BIG*, and it is unclear if NCT will keep it. The product is easy to find on a Web search yet currently unavailable so pricing information is

[133] (confluence energy, 2020)
[134] (confluence energy, 2020)
[135] (confluence energy, 2020)
[136] (BIOCHAR SOLUTIONS, n.d.)
[137] (BIOCHAR SOLUTIONS, n.d.)
[138] (Popper, 2014)
[139] (Popper, 2014)
[140] (Jones, 2020)
[141] (Jones, 2020)
[142] (Zeringue, 2019)

nonexistent. NCT says its biochar will be high-quality yet low-cost because it has big economies of scale.[143]

CERTS: USDA[144], OMRI[145]

For the Company to find profitability at a low price per ton is a good idea given the re-entrance of CP into the market. NCT will set a market price that must be addressed.

Colorado Biochar Resources (CBR) – In business since 2011, Colorado Biochar Resources is located in Pueblo, Colo., not an obvious choice for a biochar provider given its desert Southwest location. Like others, the business started out as a family-run logging operation and moved into biochar production by converting wood downed from area forest fires.[146] In addition to making biochar, owner Micah Langston sells kilns, and she's also a member of BS|C's distributed network of providers.[147,148]

It is unclear if Ms. Langston sells biochar to Pueblo's *Cannabis* grow houses, and her operation appears small from her website. Still, because CBR is woman-owned, she can jump to the head of the line with government and industrial clients looking to sell to minority and women-owned businesses first.

Pagosa Forest Products, LLC – New entrant to the field, Pagosa Forest Products, LLC (PFP) received its air pollution emissions permit from CDPHE on Feb. 3, 2020 (see Appendix E, iii). Like CBR, owner J.R. Ford is a mill owner who also sells equipment.[149] His primary focus has been on being a renewable energy provider with an original intention to build a 5-megawatt powerplant using woody biomass.[150] He uses a high-end gasifier that makes biochar secondarily.[151,152]

Mr. Ford is in the southwestern corner of Colorado where spruce beetles are ravaging forests so feedstock is plentiful.[153] He is also closer to Pueblo than any other biochar provider and therefore, proximate to the city's hub of *Cannabis* grow houses.

---

143 (Chaurasia, 2020)
144 (Bio-based News, 2016)
145 (www.CoolTerra.com, 2018)
146 (Romig, 2017)
147 (Romig, 2017)
148 (Colorado Biochar Resources, n.d.)
149 (Coyner, 2015)
150 (Coyner, 2015)
151 (COLORADO Department of Public Health & Environment, n.d.)
152 (ICM, Inc., 2020)
153 (Romeo, 2020)

Go-To-Market Strategy

As discussed in the Market Segmentation section, Metro Biochar® has three customers: 1) *stormwater overseers (SW)*, 2) *wastewater treatment providers (WW)*, and 3) *mine remediation specialists (MR)*. After over approximately 15 conversations with SW and WW professionals, it's clear SW treatment is the first sales push because of *existing* awareness about biochar's water-purifying capabilities. Fully half of SW professionals responded to the Consultant within 24 hours after receiving an initial inquiry about biochar, and all had heard of it.

<u>Product Vision</u>—Metro *Biochar® from* clean *urban wood—treats water, enriches soil, and creates a healthier planet.*

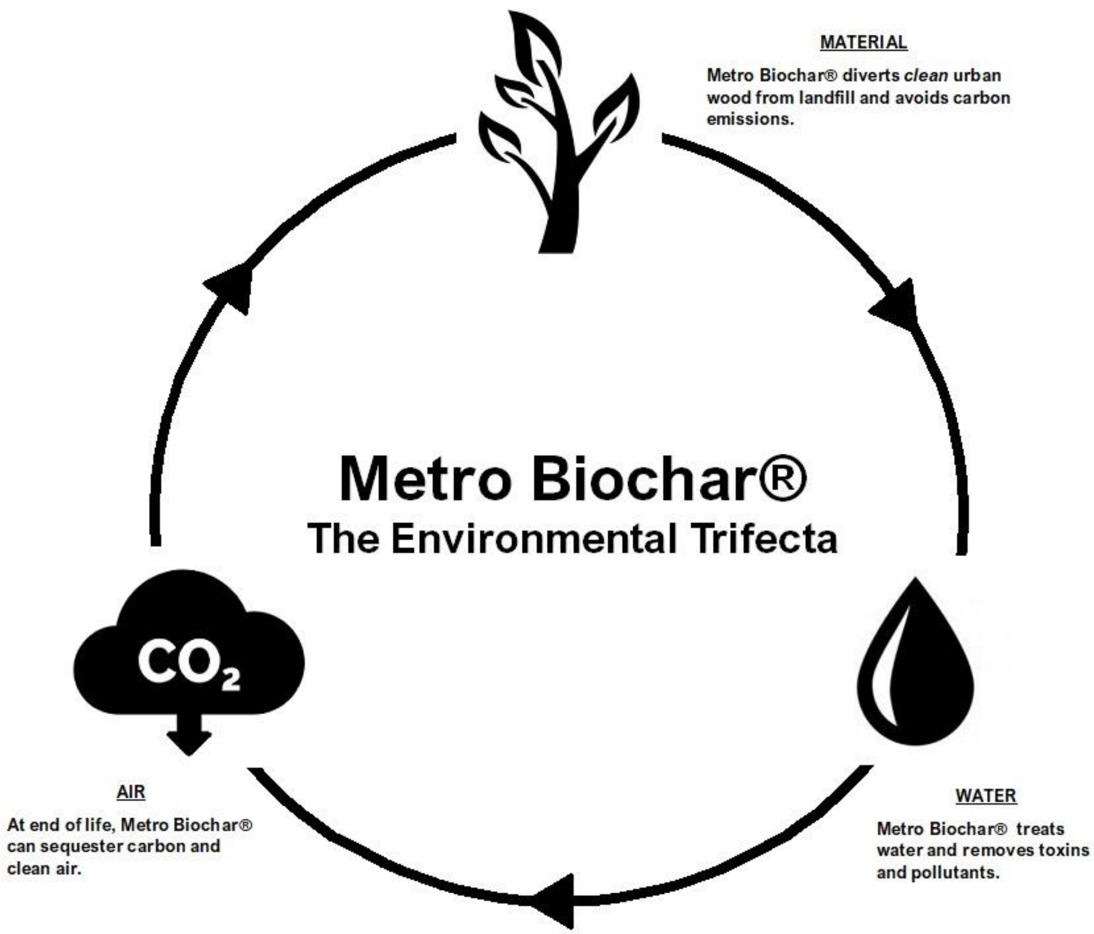


Figure 13 - Metro Biochar With Three Environmental Benefits - Material, Water & Air

(Free Icons Library, n.d.) (depositphotos, 2019)

The product vision statement addresses a number of issues succinctly.

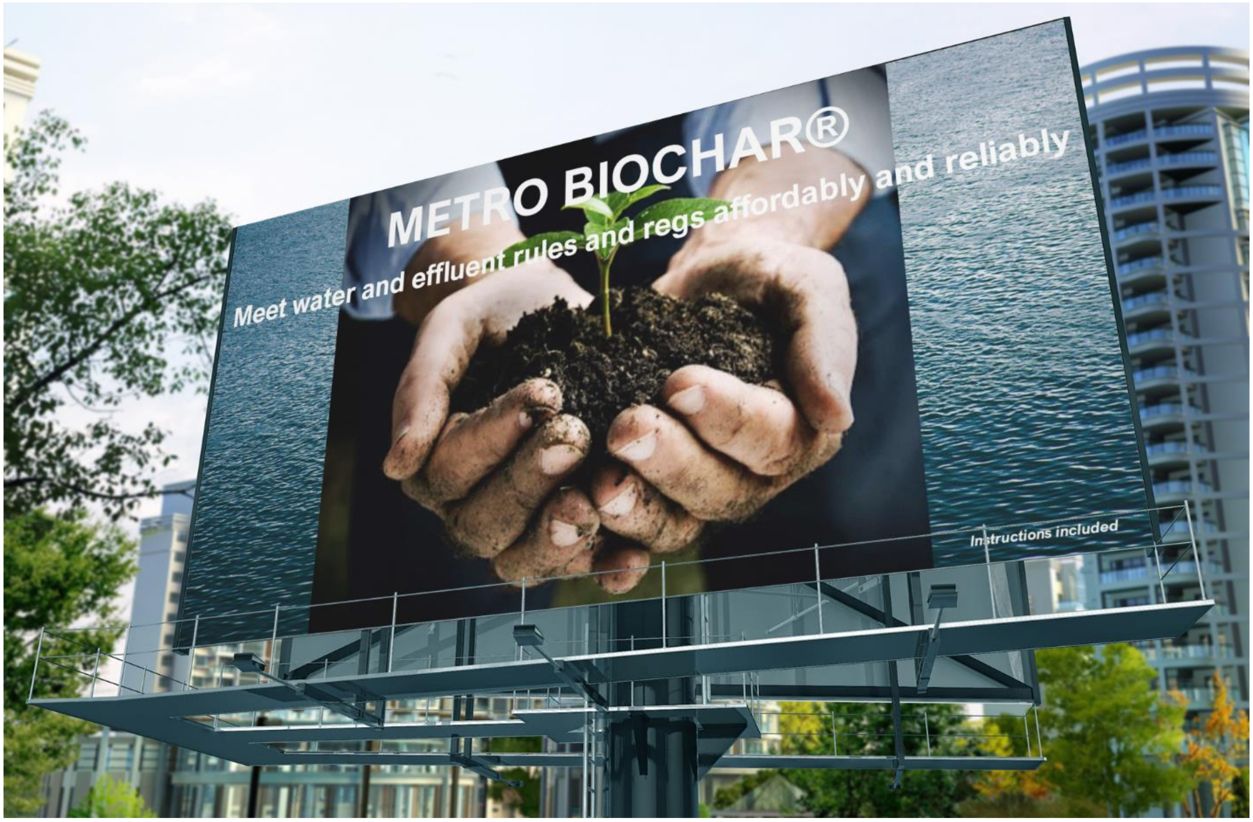
1. **States wood is *clean*** – This topic will be discussed in greater depth later, but the Consultant *highly* advises this message about "*clean urban wood"* is front and center.
2. **Covers all bases** – In Figure 5, the product vision directly and indirectly taps all four top-level sectors: agriculture, retail, water treatment, and mining reclamation. That is, anyone buying for any of these purposes will feel addressed.
3. **Bridges information gap** – While biochar may not be (well-)known to a buyer, the product vision says its source and uses.
4. **Inspires a bigger vision** – Metro Biochar® buyers are highly educated, left-brain professionals tasked with dirty, thankless cleanup of water bodies, runoff, and polluted sites. The product aspirational vision helps them see the bigger picture and feel good about their crucial work.

Value Proposition – *Meet water and effluent rules and regs affordably and reliably with technical support.*

Benefits & *Value Brought to Customer* – ***Items 1 through 3 below are differentiators specific to the Company and Metro Biochar®.*** In sum, Metro Biochar® helps buyers meet rules, regs, and budgets with locally sourced water treatment products that help the planet.

1. **Sourced locally from *clean* urban wood**
   1.1. ***Supporting local companies and resources perceived as good and possibly mandated or given preference by government entities.***
2. **Diverts *clean* wood from landfill**
   2.1. ***Reducing landfill confers good environmental cred and helps meet mandated tipping and/or emissions reductions.***
3. **Technical and use specifications (TUS) included**
   3.1. ***Instructions, use directions, and scientific backup come with product.***

Figure 14 - Metro Biochar® Value Proposition



(VadimPP, 2009) (GES GREEN EARTH SOLUTIONS, n.d.)

4. Adheres with high surface area and adsorption capacity
    4.1. *Binds effectively to regulated nutrients, organic matter, heavy metals, pathogens (including E. coli), and other contaminants.*
5. Reduces landfill emissions
    5.1. *Reducing emissions also conveys good environmental cred and may help meet mandated emissions reductions.*
6. Reduces fertilizer runoff
    6.1. *Binds to N and P.*
7. Cleans algae bloom
    7.1. *Clears water bodies of toxic algae and hypoxic zones.*
8. Outperforms activated carbon and sand
    8.1. *Provides effective new tool in cleanup arsenal.*
9. Costs less than activated carbon, sand, and labor- and electricity-intensive ultraviolet light
    9.1. *Costs less than legacy treatments to help meet tight budgets.*

10. Increases soil water retention

    10.1. More water stays in soils, less in runoff. 'Can also lessen irrigation needs.

11. Reduces non-point source pollution

    11.1. Mitigates pollutants even when source is not evident.

12. Sequesters carbon at end of life

    12.1. Can create carbon sink when spent and may help meet mandated emissions reductions.

Differentiation & Name—*Metro Biochar® is clean urban wood diverted from landfill, and technically supported.*

1. **Sourced from locally *clean* urban wood** – The Consultant crafted the brand name *Metro Biochar®*, which *alludes* to the wood's origins as urban rather than agricultural, rural, or forested. Merriam-Webster defines "metro" (metropolitan, metropolis) as "*a city regarded as a center of specified activity*."[155] Thus, urban centers are Metro Biochar's® source of (C&D) *clean* woody feedstock.

The name is also generic enough that it can travel as part of a C&D plug-and-play package to any other location in the country. No other company in Colorado sources C&D wood so, this is a key differentiator. Yet it must *always* be part of the phrase "*clean urban wood*" to head off any concern *from the very product mention* that it contains contaminants or pollutants.

Another way to draw attention to the region where the clean urban wood is sourced from is to certify with state organizations like "Colorado Proud." While most Metro Biochar® competitors source wood locally, too, not all do.[156] This adds additional brand credibility and may boost sales if region matters to a buyer.

2. **Diverts *clean* wood from landfill** – And thus, greenhouse gas emissions avoided. (This will need to be weighed against biochar pyrolysis in a lifecycle assessment (LCA) for net-carbon. Still, this is a true statement.) No one else is diverting waste streams like the Company, and the GHGs avoided can be quantified.

---

[154] (Breakenridge, 2017)
[155] (Merriam-Webster, Incorporated, 2020)
[156] (James Gaspard, personal communication, May 28, 2020)

3. **Technical and use specifications included** – Once the Consultant found a receptive, knowledgeable audience with SW providers, the top issue they stated is the absence of TUS because the BIG is present. Simply, they do not know how to apply biochar – residence times, how often to change it, amount per a given flow rate or contaminant level, etc. *In order to crack this first market (and subsequent ones), this information must be provided and credible*. Additionally, Metro Biochar® comes with cost-benefit analyses (CBAs) compared to activated carbon, ultraviolet light, and sand. No other biochar provider is doing this, yet it is needed to cinch sales. That said, Confluence Energy with Jonah Levine on board would be most likely to provide some of this data. The Company can outperform others by including this with its Metro Biochar® sales. While the buyers want scientific data, including a wrapper or some encompassing messaging that's cheeky or humorous would be an additional differentiator.

Positioning Statement—***There is no waste in nature. At 5280 Recycling Solutions, we let nature be our guide, and we create high-value products from clean, locally sourced recyclates otherwise headed for landfill. 5280 also provides technical support for commercial, industrial, and government clients to meet rules, regs, and budgets in ways that help the planet.***

<u>Who Is the Metro Biochar® Customer?</u>— The professionals the Consultant spoke with are either licensed professional engineers and/or graduate degree holders. That is, they are highly educated scientists and fluent with chemistry, left-brain, empirically and data-driven, comfortable with highly technical information, and a noticeable number were women.

Most worked for governmental organizations and some non-profits that provide oversight and/or vetted technical and use specifications. They were all located in metro Denver, though stormwater treatment and runoff are not exclusively urban issues.

Figure 15 – Metro Biochar® has been approved by Dr. Bunsen Honeydew and Beaker.

(BIGBADTOYSTORE, INC., 2020)

The SW, WW, and MR professionals work with strict environmental rules and regulations, and Metro Biochar® product failure can cost them monetary penalties, public scrutiny and censure, and possibly even facility shutdown. These customers are driven by the *behavioral characteristics* of the product – that they are relevant, consistent, and provided as needed.[157] All these professionals need reliable data in order to properly and efficiently use Metro Biochar® for water treatment and to justify the expense. *Both a cost-benefit analysis and TUS must be available for them to purchase Metro Biochar®* . As the product gains users, the Consultant advises the Company gather positive reviews about product successes.

Their Issues – There are five top pollutants and contaminants SW professionals must mitigate: 1*) nitrogen (N)*, 2) *phosphorus (P)*, 3) *E. coli*, 4) *heavy metals*, and 5) *heavy organic*

[157] (Breakenridge, 2017)

loads.[158] Additionally, several professionals mentioned two emerging CDPHE regulations they will be required to navigate soon: Regulations 31 and 85 regarding nutrient flows.[159] While the Consultant hasn't spoken to MR specialists, it is highly likely that the five pollutants mentioned above will also need addressing in the MR sector in addition to other contaminants. Lastly, the COVID shutdowns will no doubt put enormous financial burdens on municipalities as tax revenue declines. Bringing less costly yet effective biochar for water treatment can only be welcome.

Fit To Market

The Consultant has identified a warm-to-hot market segment – people who deal with stormwater – and there are a number of places to find them (see Table 5).

Table 5 – Some Customers Who Fit The Market for Metro Biochar®

FIT-TO-MARKET - INITIAL CUSTOMERS		
ORG	WHO	NO. MEMBERS
MHFD, Mile High Flood District[1]	Stormwater professionals in metro area	41 entity members
ASLA, American Society of Landscape Architects[2]	landscape architects in Colorado	136 results (<200 miles)
ASCE, American Society of Civil Engineers[3]	Civil engineers in Colorado	?
Filtration manufacturers	Manufacturers who make water filtration media: Amiad; WesTech Engineering, Inc.; Pure Aqua, Inc.	4 identified. Presumably more.

1 (Mile High Flood District, 2020) 2 (The Colorado Chapter of the American Society of Landscape Architects, 2020) 3 (ASCE Colorado Section , 2016)

One caveat in looking at this *total addressable market* (TAM) is that they either *are* or *will deal* with public and private entities.[160] That is, the MHFD, for example, embodies 41 government entities and could cover thousands of miles of waterways.[161] This list is not intended to be comprehensive but a starting point. Additionally, there may be other ways to develop customers for life.

- **Let customers help** – As research proceeds and TUS develops, engage and interview SW customers so they can help design bespoke solutions that they need to solve their specific problems. More on this is discussed in the "Marketing Plan" section.
- **Keep them in the loop** – As research continues, keep them informed, perhaps through email drip marketing or other means.

---

158 (Consultant interviews, Summer 2020, transcripts available upon request)
159 (Juliana Archuleta, personal communication, July 27, 2020)(Darren Mollendor, personal communication, July 30, 2020)
160 (Kelly, 2019)
161 (Mile High Flood District, 2020)

- **Open the door** – The Company needs customer feedback so buyers can get what they want. An open-door policy with customers is required to gain and retain their business.

As this SW market grows and develops, successes in developing it should be mirrored for MR and other sector markets.

Marketing Plan

The Metro Biochar® customers have been identified and described in the "Competition & Go-To-Market" section of this plan. Because SW professionals *recognize* biochar and see potential applications, they should be the first but not the only target market. This section is written with them in mind.

Product & Service Programs[162] – One key differentiator and selling feature is TUS – the technical and use specifications provided to Metro Biochar® customers. These should be sent to the customer with invoicing and papers sent with delivery for installers. Additionally, the Company should set up a (wo-)manned technical hotline with representatives who can answer questions. In the event a tech rep cannot answer a technical question, that should be expedited to Company employees who can, and that call should be returned within 24 hours. Technical support should be integrated with any Metro Biochar® purchase and information provided to customers quickly.

Figure 17 - Custom culvert grate

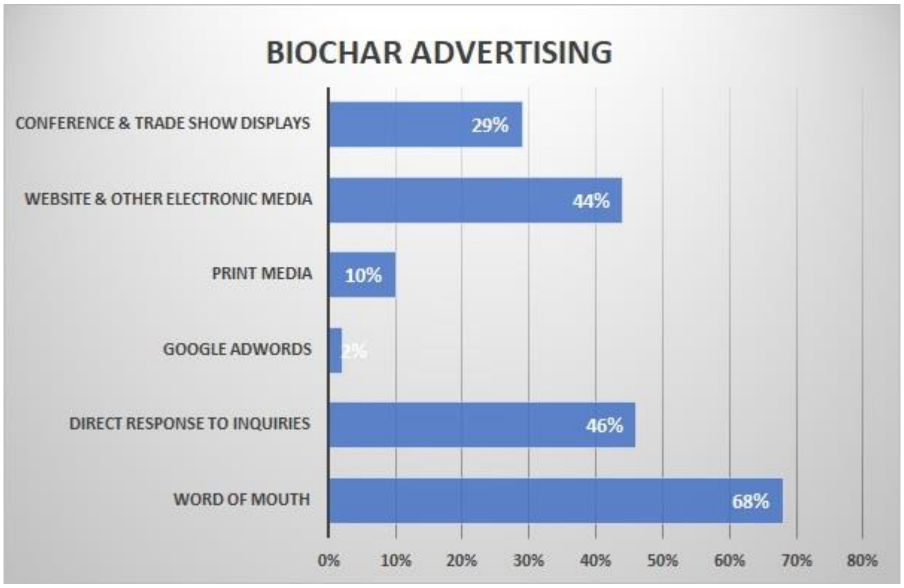
Figure 16 – Wattles Around Storm Drain

(SPEC-NET™ PTY LTD, 2017) (Industrial Products, n.d.)

[162] (Boyd, 2020)

As the Company and partners develop TUS, the Company should look for ways to provide bespoke products to SW clients, like with customized culvert filtration covers or other Metro Biochar® products (see Figure 16). Also, *wattles* (socks filled with Metro Biochar®) can be customized for specific applications – length, girth, etc. (see Figure 17) Ms. Piza from MHFD mentioned, however, that "mixing of products must be done off-site."[163] That is, any hybrid product will need to be *application-ready* to be compliant with *Volume 3.*

Figure 18 - US Biochar International 2018 Survey of Advertising Types



(U.S. Forest Service, 2018, p. 5)

Promotion & Marketing[164] **-** The Metro Biochar® customer is specific – *anyone looking for water filtration and/or mine cleanup*.

Therefore, promotional efforts should be lasered rather than scattergun. From the 2018 USBI industry survey, industry advertising is "direct, relatively traditional, and unsophisticated."[165] Figure 18 has a breakout of the various types recorded in the survey. Marketing for Metro Biochar® should come into the 21st century.

1) **Drip Marketing** – A CRM for direct customer drip email should be set up and populated. (This is discussed further in the Sales Plan section.) Emails to potential clients should contain high-value information and be sent frequently enough to foster brand

163 (Holly Piza, personal communication, Aug. 12, 2020)
164 (Boyd, 2020)
165 (U.S. Forest Service, 2018, p. 5)

recognition but not so much that they are considered annoying. And again, appropriate humor is both a differentiator and always appreciated.

2) **Trade Shows** – There are a number of organizations in Colorado (and elsewhere) with potential SW clients. The Colorado Water Conservation Board (CWCB), the Colorado Watershed Assembly, the Colorado Stormwater Council are important ones to consider for trade-show participation.[166] Participating in trade shows gets the Metro Biochar® name in front of customers. Since many customers are government employees, they will have limits on receiving gifts or schwag over a certain dollar amount. So, fun, low-cost giveaways should be considered, like small branded bags of Metro Biochar® for yard and garden use or filters for rain barrel-captured water.
3) **Trade Publications** – Media for SW professionals and members in the organizations mentioned above should be targeted for high-value articles and information on biochar. Success stories of SW districts or projects using Metro Biochar® should be pitched and written routinely.
4) **Social Media** – The Consultant is not an expert on which social media outlets are appropriate for SW professionals. This should be explored and capitalized on.
5) **SEO (Search Engine Optimization)** – In the dozens of interviews conducted so far, the Consultant noted a number of people saying they had searched online for biochar after first contact with our inquiry. It is the Consultant's experience that companies can spend lots of money badly on SEO and have little to show for it. It *is* important to be on the first page of Google (and other search engines?), and the Company should engage SEO pros with the intention of getting Metro Biochar® on the first page of Google.
6) **Dr. Bunsen Honeydew** – Explore possible product branding by the good doctor and sidekick, Beaker. This move can add humor and sophistication to the product.

Sales Channels – Sales channels should be direct by phone call or email through the Company website. All requests for information and/or orders should be handled in real-time with chat bots or other features able to engage with customers.

Additionally the sales team should have a point person who follows government entity bids and project cycles to win sales. (This is discussed further in the Sales Plan section.)

[166] (Diane Kielty, personal communication, Aug. 5, 2020)

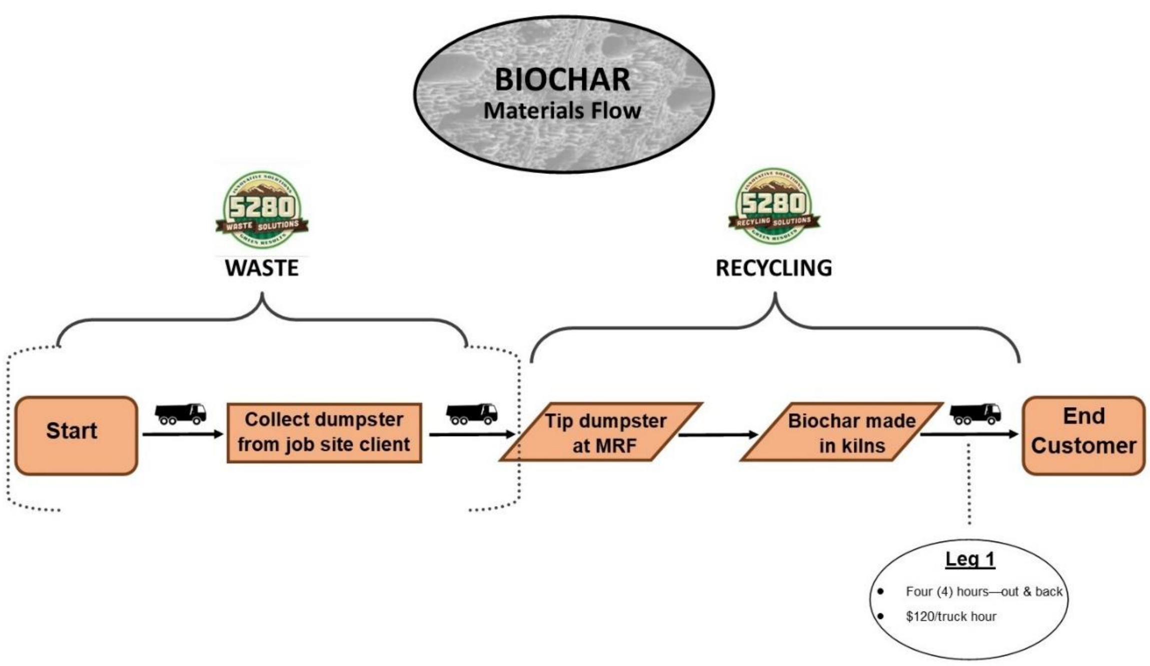
Supply Chain & Operations

Supply Chain – The supply chain for the Company is short and well-stocked. The Company says it hauls 200 to 300 30-yard, 3-ton dumpsters to landfill daily. Therefore, 200 dumpsters equals 600 tons of C&D waste daily (1.2 million pounds).

The Biochar Now kilns hold 1.15 tons of clean shredder wood.[167] With 20 kilns and one burn cycle per day, the kilns need 23 tons of clean, shredded wood per day, or 3.8 percent of the Company's total hauls. If the Company runs two burn cycles per day, the kilns require 46 tons of wood daily, or 7.6 percent of the total daily haul. Therefore, supplying clean urban wood for daily biochar production is less than 10 percent of 5280 Waste Solutions' daily hauls.

Materials Flow – The Company is centralizing its tipping and biochar operations on one site, which will also cut down on transportation (see Figure 19). Since 5280 Waste Solutions is a waste-hauling *transportation* company, the Consultant suggests it deliver product to the end customer, fee to be determined.

Figure 19 - Biochar Materials Flow Between the Two 5280 Companies



167 (James Gaspard, personal correspondence, June 26, 2020)

Operations – While the Company is new to biochar production, the Company has the operational model shared by Mr. Gaspard at Biochar Now. This information is appended in the back (see Appendix D, ii).

Sales Plan

Working With The Government – SLED buyers are "state, local, and education" government entities, and the ones that the Consultant spoke to knew about biochar.[168] These .gov employees did not understand, however, how to use it.

U.S. SLED buyers spend $1.5 trillion annually on goods and services.[169] As the Company facilitates the development of TUS for Metro Biochar® to get these written into best-practices manuals like MHFD's *Volume 3*, the Company needs to prepare for sales to government. Anything the Company would do to prepare for sales to the *federal* government (which is not currently recommended) should be done for sales to *local* and *regional* governments.

- **Legal entities** – Create and register.
- **EIN** – Secure.
- **NAICS codes** – Find. The Consultant put together a quick list here (see Table 6), though more time should be allotted to this.
- **DUNS number** – As soon as possible.
- **Business certifications** – Are there certifications that will help the business? If so, they should be sought as they can give preferential treatment on government contract bids.
- **CRM** – Identify and emplace CRM. Start populating.

[168] (Grady, Deanna, 2019)
[169] (Grady, Deanna, 2019)

Table 6 – NAICS Codes for Metro Biochar®

NAICS #	TITLE	SECOND LEVEL
221310	Water Supply and Irrigation Systems	-Filtration plant, water -Water treatment and distribution
237110	Water and Sewer Line and Related Structures Construction	-Construction management, water and sewage treatment plant -Lagoon, sewage treatment construction -Storm sewer construction -Water filtration plant Construction
238910	Site Preparation Contractors	-Dewatering contractors -Drainage system (e.g., cesspool, septic tank) installation -Mine site preparation and related construction activities, construction contractors -Septic system contractors
237990	Other Heavy and Civil Engineering Construction	-Land drainage contractors
562910	Remediation Services	-Environmental remediation services -Mine reclamation services, integrated (e.g., demolition, hazardous material removal, soil remediation, revegetation) -Oil spill cleanup services -Remediation services, environmental -Site remediation services -Toxic material abatement services

(NAICS Association, 2018)

Local & Regional .Gov Buyers – The Company should identify all 41 SW entity members in MHFD. Also find other SW entities and providers across Colorado. Research state (and regional) dates for budget cycles (fiscal year). The *federal* government's fiscal year ends in September, and its buying season is July through September, with the majority of buying lumped at the beginning and end of that cycle.[170] All this should be completed by first production.

Local & Regional .Com Buyers & Partners – In addition to .gov buyers, there are also private industry professionals who can recommend Metro Biochar® to their *government* clients. The Consultant has had conversations with half a dozen such pros with the (un-)surprising result that they, too, suffer from the BIG.

Industry professionals who should be targeted and will no doubt need TUS are SW engineers (and their firms), landscape architects who must deal with site drainage and effluent runoff, and filtration manufacturers (see Table 5). There may be others. The Company should identify as many of these across Colorado as possible and enter them into the CRM for further contact. Also, some of these professionals may be interested in partnering with the Company to sponsor and/or create TUS to speed market adoption of Metro Biochar®.

---

170 (Grady, Deanna, 2019)

Regulations

Colorado Department of Public Health and Environment, Air Pollution Emission Notice (APEN) – The biochar pyrolysis process, while largely oxygen-free, does create emissions, and the State of Colorado CDPHE requires emitters to obtain a "construction" APEN permit if emissions exceed specified thresholds.[171] The City and County of Denver, where the facility will reside, is in a *non-attainment zone* with lower emission ceilings.[172] *Therefore, the Company must apply for a permit, which can take as long as six months to receive.*[173] *This element of the rollout is critical path, and "technically nothing permanent is supposed to go in before the permit is issued, so no buildings."*[174] *The Company should designate a point person to shepherd this process even when hiring an outside engineer to vet the APEN submission – a good idea that can expedite acceptance.*

Appendix E (i, ii) show the calculations for the permit based on COLORADO Air Pollution Control Division, Permit number: 15WE1395, April 25, 2018, for Biochar Now (10 kilns). The Consultant made adaptations to fit this to the Company's specific needs. It is unclear if this permit is public record so, the Consultant appends it, along with a new construction permit for Pagosa Forest Products, LLC, at the back of this plan.

Briefly, the Company needs to pay a one-time permit fee of $216, permit processing of $108.12 (estimated at 8 hours), and fees per ton for both *criteria* and *non-criteria* pollutants. The approximate total for 20 kilns is $1,681.49 (see Appendix E, i). Also, APENs are renewed every five years so, the Company must estimate year-on-year production growth.[175] *That said, the permit encompasses that growth in both calculations and fees, and they must be paid in full every year. In other words, overshoot can cost the Company needlessly from the first year on*.

Once the Company resolves all real estate and financial issues, this process should begin immediately. The urgency of this cannot be overstated. No biochar can be produced without an APEN. There will be other ordinances the Company must adhere to based on site chosen and authorities having jurisdiction (AHJs).

---

[171] (COLORADO Department of Public Health & Environment, 2019)
[172] (COLORADO Department of Public Health & Environment, 2019)
[173] (Aaron Moseley, personal correspondence, Spring 2020)
[174] (Aaron Moseley, personal correspondence, July 30, 2020)
[175] (COLORADO Department of Public Health & Environment, 2019)

Financials

A 2011 paper explored the NPV in a number of scenarios for Colorado's Biochar Solutions.[176] The authors found that *the price of biochar was the number one determinant of NPV* (and profitability).[177] The *second most important factor was labor cost*.[178] Biochar Solutions also assumed a sale price of biochar (in 2011) at $2.20 per kilogram ($1 per pound, or $2,000 per ton).[179]

This paper is appended at the back of this plan (see Appendix E), and in like mind, the Consultant considered a number of options in determining financial feasibility for Metro Biochar®. It is the Consultant's opinion that Biochar Now's financial data given to the Company is optimistic, and the Consultant adjusted this data with the following assumptions.

Table 7 – Assumptions & Options Used In Financial Modeling

SUMMARY	UNIT	$/LB
Burns per day	2.00	
INPUT (woody biomass) - Tons per Biochar Now kiln (de: 5280 - Biochar_Calcs-MAB)	1.15	
OUTPUT (biochar) - Tons per Biochar Now kiln (de: 5280 - Biochar_Calcs-MAB)	0.29	
OUTPUT (biochar) - Lbs per Biochar Now kiln (de: 5280 - Biochar_Calcs-MAB)	575	
(A) Price per ton biochar / per pound	300	$ 0.15
(B) Price per ton biochar / per pound	500	$ 0.25
(D) Price per ton biochar / per pound	600	$ 0.30
(C) Price per ton biochar / per pound	800	$ 0.40
(E) Price per ton biochar / per pound	1,200	$ 0.60
(F) Price per ton biochar / per pound	1,500	$ 0.75
(G) Price per ton biochar / per pound	2,000	$ 1.00
Y1 SALES - 50%	50%	100%
Y2 SALES - 65%	65%	100%
Y3 SALES - 80%	80%	100%
Monthly sales (USE "price-per-ton" from scenarios in dropdown menu, derived from SUMMARY table)		
$0.75		

[176] (Kim, Anderson, & Chung, 2015)
[177] (Kim, Anderson, & Chung, 2015, p. 194)
[178] (Kim, Anderson, & Chung, 2015, p. 194)
[179] (Kim, Anderson, & Chung, 2015, p. 192)

- **Price** – Mr. Gaspard says he gets $1 per pound for his product ($2,000 per ton).[180] The 2018 US Biochar Industry (USBI) survey says its most "often cited price" is $1,600 per ton.[181] It has been difficult to find other bulk pricing regionally for biochar. Neither Confluence Energy nor Colorado Biochar Resources have responded to several inquiries. NCT has removed prices for coolterra. To err towards conservative net-income projections, the Consultant assigned a high price of $1,500 per ton – the USBI price slightly adjusted downward. Table 7 shows drop-down assumptions made and iterations calculated.

- **Year 1 (Y1)** – Because APEN will take approximately six months to process, the Consultant assumed production would start midway in Y1 – June 2021.

- **Kiln Capacity** – Mr. Gaspard rounded up his kiln output to 600 pounds of product per burn cycle. Based on the data given to the Consultant, a more accurate number is 575 pounds of biochar per cycle.

- **Burn Cycles** – Mr. Gaspard assumes three burn cycles per day. The Consultant modeled both one and two.

---

180 (James Gaspard, personal communication, May 28, 2020)
181 (U.S. Forest Service, 2018, p. 6)

- **Sales Projections** – It is difficult to estimate Y1 sales so, the Consultant assumes 50 percent sales in that time period. Because the CAGR is increasing at approximately 15 percent per year, the Consultant assumed this is a run rate and that sales will climb at that level. Given that Mr. Levine estimates sales are *doubling every year in Colorado*, the 15 percent number is conservative.

Table 8 - Summary of Financial Analyses Considering Burn Cycles Per Day, Price Per Ton & Sales Projections

1X BURN PER DAY			
PRICE PER TON	**Y1 (50% Sales)**	**Y2 (65% Sales)**	**Y3 (80% Sales)**
$ 1,500	$ (2,526,498)	$ (1,891,190)	$ (1,483,429)
$ 800	$ (2,721,711)	$ (2,750,042)	$ (2,534,147)
$ 500	$ (2,805,373)	$ (3,116,338)	$ (2,996,005)
2X BURNS PER DAY			
PRICE PER TON	**Y1 (50% Sales)**	**Y2 (65% Sales)**	**Y3 (80% Sales)**
$ 1,500	$ (2,097,786)	$ 586,082	$ 1,419,485
$ 800	$ (2,488,211)	$ (1,139,654)	$ (690,343)
$ 500	$ (2,655,536)	$ (1,872,245)	$ (1,597,996)
1X BURN PER DAY			
PRICE PER TON	**Y1 (100% Sales)**	**Y2 (100% Sales)**	**Y3 (100% Sales)**
$ 1,500	$ (2,108,186)	$ (909,172)	$ (907,935)
2X BURNS PER DAY			
PRICE PER TON	**Y1 (100% Sales)**	**Y2 (100% Sales)**	**Y3 (100% Sales)**
$ 1,500	$ (1,261,161)	$ 2,542,086	$ 2,562,083

Note: Numbers derived from Biochar Now's pro forma given the Company with adjustments made by the Consultant. Equipment depreciation was not factored.

- **Results** – Briefly, one burn cycle per day is not feasible at a price of $1,500 per ton nor at any lower price (see Table 8). If the 15 percent run rate holds true, the Company must operate two kiln cycles per day.

With two kiln burn cycles and pricing at $1,500 per ton, the Company will see profit in Y2 and beyond. And if the Company sells 100 percent of product from Y1 on, the business is profitable.

- **Activated Carbon Opportunity** – *As has been discussed, both AC and UV are expensive legacy treatments that are ripe for displacement in whole or part.* When the

Company rolls out bespoke solutions catering to SW and MR customers, the sales price of $1,500 per ton of product may be able to be raised. Also, it will be critical to keep a watchful eye on National *Carbon* Technologies (NCT) as it has to be assumed it is considering this, too. Cost-benefit analyses of legacy solutions may support higher pricing as biochar tonnage may be hidden in Metro Biochar's® (blended) products. (See Appendix D, i for financial data.)

Energy for Biochar & Energy Prices – In the Consultant's decade-long experience with building energy efficiency, propane is usually a flashing red light as a cost-prohibitive way to heat, cool, and power. With that in mind, the Consultant worked with Mr. Gaspard about the possibility of switching kiln fuel from propane to natural gas (NG), a transition he says is possible. Propane is an obvious choice in rural or undeveloped areas as there is no NG transmission infrastructure. When the Company decides on a(n urban) site, it will presumably have that.

Table 9 - Fuel Types & Costs for Natural Gas & Propane

FUEL TYPES & EXPENSE			
Schedule	Service & Facility Charge (Monthly)	Usage Charge (Per Therm)	Fuel Expense Per Year (Based on Therms Needed)
Propane		$ 0.38462	**$ 105,000**
Commercial Small Gas (CSG)	$ 43.88	$ 0.11585	**$ 77,783**
Commercial Large Gas (CLG)	$ 110.15	$ 0.87300	**$ 583,492**

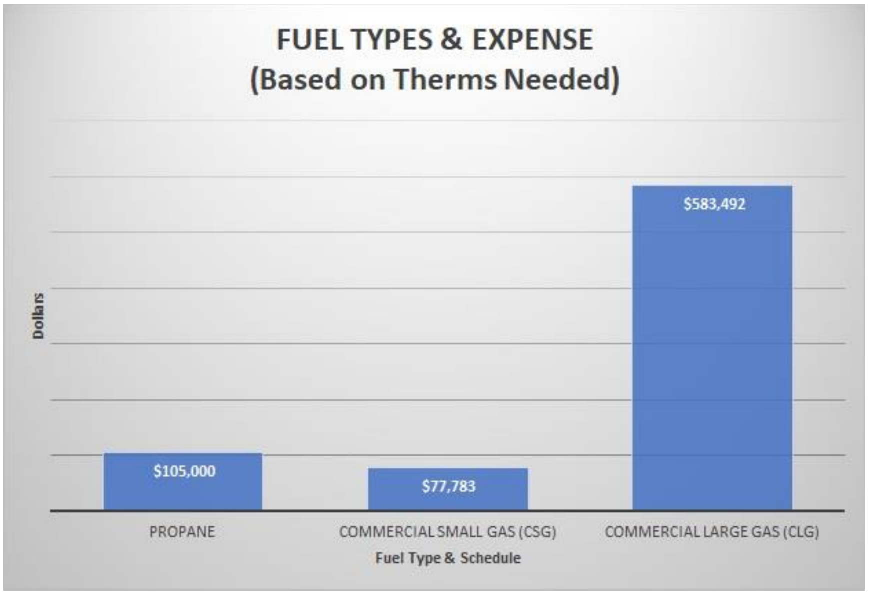
Note: Updated information was provided to this citation and is appended at bhe back of this plan. (Xcel Energy, Inc., 2020)(James Gaspard, personal communication, July 22, 2020)

The Consultant created a pricing model for propane and NG with surprising results (see Table 9 and Figure 20). Briefly, Xcel Energy's pricing for commercial small gas (CSG) per therm is $0.11585, and for commercial large gas (CLG) is $0.87300, an order of magnitude larger.[182] The tripwire between the two is 50,000 therms of gas used annually.[183] With even a minimum number of kilns used (n=10), the gas use is 555,713 MMBTUs (5,557,130 therms). Therefore, the project would operate under the CLG category, and the Consultant does not recommend a switch to NG.

[182] (Xcel Energy, Inc., 2020)
[183] (Xcel Energy, Inc., 2020)

Because the biochar process is fueled by hydrocarbons, it is instructive to think of the pyrolysis process as heavy industry – like steel or cement manufacturing. Hydrocarbons can reach and sustain high temperatures and process materials more quickly.[184] And it may be important to get to market fast with Mr. Gaspard's kilns to establish proof of concept.

Figure 20 – Bar Chart Showing Fuel Types & Costs for Natural Gas & Propane



(Xcel Energy, Inc., 2020)(James Gaspard, personal communication, July 22, 2020)

That said, the Consultant strongly advises the Company explore other pyrolysis carbonizers. The fact that Mr. Gaspard's waste-heat stack temperatures run at 2,000°F indicates extreme system inefficiencies.[185] One system, Biogreen by ETIA ECOTECHNOLOGIES, is electric, though the Consultant hasn't explored it in depth yet.[186] Also, *clean* (renewable-electrolyzed) hydrogen is making inroads into heavy industry like steel and cement manufacturing, and the Company should keep vigilant for a switch to this or other clean-fuel systems.

Environmental Achievement & Reporting

5280 Recycling Solutions has the stated mission of "creating a thriving business while doing what's right." With biochar's re-popularization in the last decade, the Company has firmly planted a big flag for environmental good. There are some ways to demonstrate that and some considerations to address further.

---

[184] (Wendy Hoenig, personal communication, June 30, 2020)
[185] (Doug Mischlich, personal correspondence, July 27, 2020)
[186] (ETIA ECOTECHNOLOGIES)

- **Carbon footprint** – As has been discussed, biochar pyrolysis using propane and other hydrocarbons offsets carbon emissions reductions, and Mr. Gaspard's pyrolyzing kilns use approximately 6.5 million BTUs (MMBTUs) per 10-hour kiln cycle.[187]

Table 10 – Estimates on Tons CO_{2-eq} Saved & Burned – Landfill, Recycling & Pyrolysis

	METRIC TONNES CO_2			
MATERIAL	LANDFILL	LANDFILL -> RECYCLING	BIOCHAR PYROLYSIS	BIOCHAR NET
1 (short) ton dimensional lumber put in landfill	(1.01)			
$MTCO_2$ added/reduced from landfilling[1]		(1.01)		
$MTCO_2$ added/reduced from recycling[1]		(2.47)		
Net gain/loss from recycling (to biochar)		(1.46)		
MMBTUs per kiln cycle			6.5	
Propane kg CO_2 $MMBTU^{-1}$ (2)			62.87	
kg MT^{-1} (metric tonne)			0.001	
TOTALS (MT)	**(1.01)**	**(1.46)**	**0.409**	**(1.05)**

1 (EPA United States Environmental Protection Agency, 2019) 2 (The Climate Registry, 2018)

Table 10 shows a thumbnail (*rough*) estimate of metric tonnes of carbon produced and/or saved. The "landfill" column shows that dumping 1 (U.S. short) ton of wood in landfill *sequesters* 1.01 metric tonnes (MT) of CO_{2-eq}. If that same ton is *recycled* (assumed to be diverted from landfill), the net gain (loss) of CO_{2-eq} is -1.46 MT (carbon equivalents *sequestered*). But when the propane pyrolysis process happens, an additional 0.409 MT CO_{2-eq} is added, resulting in a rough net-negative CO_{2-eq} of -1.05 MT. *Essentially, using propane to convert woody biomass to biochar creates almost half a tonne of CO_{2-eq} with every kiln burn cycle*. This offsets the carbon-sequestering benefits of biochar.

These are high-level thumbnail numbers meant for direction only and leave out transportation, processing, etc. As the Metro Biochar® processes are standardized, the Company should hire a consultant to do a lifecycle assessment (LCA) on the entire supply chain. This will provide third-party verification of the Company's processes that can be presented as credible externally. As has also been mentioned, the Company should also explore non-polluting pyrolysis as these technologies become available.

The United Nations Sustainable Development Goals (SDGs) – In 2012, the United Nations Conference on Sustainable Development began work on what are known as the SDGs – goals that

---

[187] (James Gaspard, personal communication, July 23, 2020)

address the most urgent political, economic, and environmental issues facing the planet.[188] Figure 21 shows the 17 goals, and they have breathtaking scope like ending poverty, fostering decent work and economic growth for all, and protecting marine life.[189]

In order to achieve these goals before 2030, businesses must participate in a robust, credible way if for no other reason, then because Millennials expect it.[190] This cohort is now the largest part of the world's population, and SDGs are one way to address the concerns of this burgeoning group of consumers.[191] Also, Metro Biochar® SW customers are scientifically aligned.

The Consultant made a pass through the goals and identified Goals 6, 9, and 12 as aligned with the Company's business, with Goal 13 as a *possible* reach, also. The Consultant also recommends the Company make a credible commitment to furthering the SDGs and use them as an environmental yardstick, aligning as much business practice with them as possible.

Circular Processes & Economics – Figure 10 shows the potential loop of woody biomass to biochar, which (for now) is intended to treat water, a scarce resource here and elsewhere. If, however, toxins, pollutants, and pathogens are accumulated beyond to-be-determined thresholds from evolving TUS, Metro Biochar® will function more like a paper towel, sopping up undesirable messes and then deposited in *industrial* landfill.

Beyond business profit-making, are there net environmental benefits if that happens? Wood is reused to clean water, and no one will argue that is detrimental. But is there anything else?

The highest and best, fully environmental use for Metro Biochar® is that it ultimately become soil amendment and thus, a carbon sink. Yet the agricultural market in Colorado is not a feasible target for the Company now, and it may never be. Also, true circularity foregoes fossil fuels, and for now with the technologies available, this also is not possible.[192]

Therefore, it is defensible to say that Metro Biochar® can create a complete environmental loop – material to water to air. But it is not a true circular product. It *is* fair to say, though, that the biochar process *bends an arc* from linear consumption, thus creating environmental good.[193]

---

[188] (United Nations Development Programme, 2020)
[189] (UNITED NATIONS, n.d.)
[190] (Cheng, 2019)
[191] (Cheng, 2019)
[192] (ELLEN MACARTHUR FOUNDATION, 2019, p. 28)
[193] (Carrie Snyder, personal communication, Aug. 12, 2020)

Figure 21 – The United Nations Sustainable Development Goals (SDGs)

(UNITED NATIONS, n.d.)

Metrics, KPIs & EPIs

KPIs, Financial – Is the Company meeting or exceeding its sales goals at outlined in “Financials, Sales Projections”? Basically, 50 percent of product produced is *sold* in Y1, 65 percent in Y2, and 80 percent in Y3. The Consultant believes these re easy targets to supersede.

KPIs, Environmental (EPI) – Because of the Company’s environmental emphasis, awareness, and intention, environmental KPIs (EPIs) should be measured and rewarded, too.

- **Closing the Loop** – Figure 10 shows the Metro Biochar® environmental loop. If Metro Biochar® is used to remediate pollutants and then disposed to landfill, the environmental benefit stops there. If it closes the loop by going into permanent siting (agriculture, golf courses, etc.), the loop is closed, and CO_2 is sequestered. This creates a carbon sink. This calculation can easily be worked into sales software and commissions and should be rewarded, yet true “end of life” for Metro Biochar® must be carefully vetted to be credible.
- **Tons Wood Diverted from Landfill** – At year end, calculate tons wood diverted and provide company-wide bonuses.
- **Water treated (gallons/cubic feet per minute/acre feet)** – In customer follow-up survey, find out how customers are using Metro Biochar®. If that is in water treatment, calculate amount of water treated, and provide company-wide bonuses.
- **Discretionary** – Special bonuses are a plus and can be awarded for accomplishments like reducing energy, carbon, water, and waste from operations. Any enterprising employee who finds a non-hydrocarbon-based pyrolizer that makes financial sense should receive a big, BIG bonus.

Roadmap With Milestones

See Appendix A for the project roadmap. Because the rollout has so many moving parts with so many big questions unanswered, the Consultant created two projects phases: Phase 1 with preconstruction and pre-production processes, and Phase 2 when Metro Biochar® production begins.

There are also four broad activity categories identified:

- Real estate & fixed assets – Completing real estate and MRF equipment purchase

- Market, research & technical/use specifications development – TUS work should begin as soon as the green flag is waved.
- Sales & marketing – Customers are well-identified, and a CRM can be populated. It's also incumbent to begin market development in other sectors.
- Production – First production.

The APEN permit is critical path as are real estate site transactions and MRF sorting equipment. 'Best case, the project can be in production June 1, 2020.

# # #

References

5280 Recycling Solutions. (2019). *5280 Front C&D Recycling Leader*. Retrieved Nov. 21, 2019, from 5280 Recycling Solutions: https://5280recycling.mtmdevbox.com/

ACUMEN RESEARCH AND CONSULTING. (n.d.). *Industrial Wastewater Treatment Market to Surge Beyond $16.5 Bn by 2026*. Retrieved June 23, 2020, from ACUMEN RESEARCH AND CONSULTING: https://shindesa-work.colibriwp.com/acumenresearchreports/industrial-wastewater-treatment-market/

ASCE Colorado Section . (2016). *ASCE American Society of Civil Engineers Colorado Section*. Retrieved Aug. 11, 2020, from ASCE Colorado Section: http://www.coloradoasce.com/wp2/2016/05/08/environmental-water-resources-institute/

BBI International. (2019, July 30). *Sale of Confluence Energy Wood Pellet and Bioproducts Manufacturing Facility*. Retrieved July 27, 2020, from EIN PRESSWIRE: https://www.einpresswire.com/article/492148926/sale-of-confluence-energy-wood-pellet-and-bioproducts-manufacturing-facility

BIGBADTOYSTORE, INC. (2020). *The Muppets Select Bunsen Honeydew & Beaker BBTS Exclusive Production Run*. Retrieved Aug. 4, 2020, from BIGBADTOYSTORE: https://www.bigbadtoystore.com/Product/VariationDetails/89844

Bio-based News. (2016, Feb. 22). *Cool Terra earns the USDA Certified Biobased Product Label*. Retrieved Aug. 13, 2020, from Bio-based News: http://news.bio-based.eu/cool-terra-earns-the-usda-certified-biobased-product-label/

Biochar Now. (n.d.). *Biochar Can Beneficially Change The World.* Retrieved July 8, 2020, from Biochar Now: http://biocharnow.com/

BIOCHAR SOLUTIONS. (n.d.). *HOME*. Retrieved July 8, 2020, from BIOCHAR SOLUTIONS: http://www.biocharsolutions.com/

Boyd, D. (2020, Jan. 3). *Writing a Marketing Plan*. (LinkedIn Corporation ©) Retrieved Aug. 9, 2020, from LinkedIn LEARNING: https://www.linkedin.com/learning/writing-a-marketing-plan-2/next-steps?u=2194065

Breakenridge, D. (2017). *Create a Go-To-Market Plan*. (L. C. ©, Producer) Retrieved Aug. 3, 2020, from LinkedIn LEARNING: https://www.linkedin.com/learning/create-a-go-to-market-plan/welcome?u=2194065

Brown, J. (2018, Sept. 17). *Coloradans generate 9.6 pounds of trash per person, per day. Where does it all go?* Retrieved Nov. 21, 2019, from THE COLORADO SUN: https://coloradosun.com/2018/09/17/where-does-colorados-trash-go/#:~:targetText=The%202%2C364%2Dacre%20landfill%20east,and%2020%20percent%20manufacturing%20waste.

CDPHE COLORADO Department of Public Health & Environment. (2019). *2018 Colorado recycling totals*. Retrieved March 4, 2020, from CDPHE COLORADO Department of Public Health & Environment: https://www.colorado.gov/pacific/cdphe/2018-colorado-recycling-totals

CharGrow. (2018, Oct. 13). *Biochar vs. Charcoal vs. Activated Carbon: What They Are & How They Work*. Retrieved June 23, 2020, from CharGrow: https://char-grow.com/biochar-vs-charcoal-vs-activated-carbon#:~:text=Biochar%20is%20intended%20for%20agricultural,biomass%20in%20a%20similar%20manner.

Chaurasia, N. (2020, June 17). *Cool Planet sells biocarbon business to National Carbon Technologies*. Retrieved July 27, 2020, from aeresearch: https://www.aeresearch.net/cool-planet-sells-biocarbon-business-to-national-carbon-technologies

Cheng, M. (2019, June 19). *8 Characteristics of Millennials That Support Sustainable Development Goals (SDGs)*. Retrieved Aug. 11, 2020, from Forbes: https://www.forbes.com/sites/margueritacheng/2019/06/19/8-characteristics-of-millennials-that-support-sustainable-development-goals-sdgs/#499e772729b7

CO CDPHE. (2017, Oct.). *Reporting Your Air Emissions and Applying for Air Permits Step-By-Step for Colorado Businesses.* Retrieved July 21, 2020, from CO CDPHE: https://www.colorado.gov/pacific/sites/default/files/AP_Air-Permits-Step-By-Step.pdf

COLORADO Air Pollution Control Division. (2019). *Emissions and permitting fees.* Retrieved July 21, 2020, from COLORADO Department of Public Health & Environment: https://doc-14-2o-appsviewer.googleusercontent.com/viewer/secure/pdf/3j21ng6vl2vvq5tj7f1l02sg9u9n5ven/972nhj1gh3bbkfe916qu9rd96medps8l/1595372325000/drive/12516171842079741916/ACFrOgBEMrZ_A3b2bEAvFOo5_-3D2oV1dy1cZF6WVbDG56R23zYBYj_5yVSy1btZqr454f348BM34Q

Colorado Biochar Resources. (n.d.). *Contact Us*. Retrieved July 8, 2020, from Colorado Biochar Resources: http://www.colobiochar.com/index.html

COLORADO Department of Agriculture. (2019). *35th ANNUAL 2019 COLORADO FARM FRESH DIRECTORY.* Retrieved April 25, 2020, from COLORADO Department of Agriculture: https://www.colorado.gov/pacific/sites/default/files/Colorado%20Farm%20Fresh%20Directory_1.pdf

COLORADO Department of Public Health & Environment. (2019). *APENs and air permits* . (S. o. Colorado, Producer) Retrieved April 24, 2020, from COLORADO Department of Public Health & Environment: https://www.colorado.gov/pacific/cdphe/air/apens-and-permits

COLORADO Department of Public Health & Environment. (2020, Feb. 14). *DEPARTMENT OF PUBLIC HEALTH AND ENVIRONMENT Air Quality Control Commission REGULATION NUMBER 3 Stationary Source Permitting and Air Pollutant Emission Notice Requirements.* Retrieved July 29, 2020, from COLORADO Department of Public Health & Environment: https://drive.google.com/file/d/1_0oq-e_bYz_DT1y9h_rwn-O3gPQmQqa-/view

COLORADO Department of Public Health & Environment. (n.d.). *COLORADO Environmental Records*. Retrieved July 18, 2020, from COLORADO Department of Public Health & Environment: https://environmentalrecords.colorado.gov/HPRMWebDrawer/Record?q=PermitPkg%3A18AC0984&sortBy=

COLORADO Hazardous Materials & Waste Management Division. (2018, Summer). *Construction and Demolition Waste Survey Results.* Retrieved March 5, 2020, from Colorado Environmental Records: https://environmentalrecords.colorado.gov/HPRMWebDrawerHM/RecordView/423800

Colorado Secretary of State. (2020). *Colorado Secretary of State*. Retrieved July 18, 2020, from Colorado Secretary of State: https://www.sos.state.co.us/

confluence energy. (2020). *High quality, low cost enviromental solutions for industry and home*. Retrieved July 27, 2020, from confluence energy: http://www.confluenceenergy.com/

ConstructConnect, Inc. (2018). *Municipal Water and Wastewater Facility Project Index in Colorado*. (ConstructConnect, Inc.) Retrieved May 18, 2020, from CMD ConstructionMarketData: https://www.cmdgroup.com/building-types/water-treatment/colorado/projects/

Cottom, T. (2018, Nov. 16). *Colorado produces record level of waste in 2017*. Retrieved Nov. 21, 2019, from CONSTRUCTION & DEMOLITION RECYCLING: https://www.cdrecycler.com/article/colorado-waste-recycling-diversion/

Coyner, B. (2015). *Colorado Woody Biomass Plant Plays Waiting Game*. Retrieved July 26, 2020, from TIMBER WEST: https://forestnet.com/TWissues/2015_nov_dec/biomass.php

DeannaCat. (2020, Feb. 27). *Raised Garden Beds vs. In-Ground Beds: Pros & Cons*. Retrieved June 23, 2020, from HOMESTEAD and chill: https://homesteadandchill.com/raised-garden-beds-pros-cons/

depositphotos. (2019, June 27). *CO2*. Retrieved Aug. 13, 2020, from depositphotos: https://depositphotos.com/278560990/stock-illustration-black-co2-emissions-in-cloud.html

Electricity Local. (2020). *Electricity Local Home > States > Colorado > Berthoud*. Retrieved July 2, 2020, from Electricity Local: https://www.electricitylocal.com/states/colorado/berthoud/

ELLEN MACARTHUR FOUNDATION. (2017). *OUR MISSION IS TO ACCELERATE THE TRANSITION TO A CIRCULAR ECONOMY*. Retrieved Feb. 16, 2020, from ELLEN MACARTHUR FOUNDATION: https://www.ellenmacarthurfoundation.org/

ELLEN MACARTHUR FOUNDATION. (2019). *COMPLETING THE PICTURE HOW THE CIRCULAR ECONOMY TACKLES CLIMATE CHANGE*. Retrieved Aug. 15, 2020, from ELLEN MACARTHUR FOUNDATION: https://www.ellenmacarthurfoundation.org/assets/downloads/Completing_The_Picture_How_The_Circular_Economy-_Tackles_Climate_Change_V3_26_September.pdf

ELLEN MACARTHUR FOUNDATION. (2019, March). *URBAN BUILDINGS SYSTEM SUMMARY.* Retrieved Feb. 16, 2020, from https://www.ellenmacarthurfoundation.org/assets/downloads/Buildings_All_Mar19.pdf

Enaime, G., Baçaoui, A., Yaacoubi, A., & Lübken, M. (2020, May 18). Biochar for Wastewater Treatment - Conversion Technologies and Applicatiopns. *Applied Sciences, 10*(10), 1-29. doi:10.33990/app10103492

EPA United States Environmental Protection Agency. (2019, Nov. 12). *Waste Reduction Model (WARM)*. Retrieved Aug. 11, 2020, from EPA United States Environmental Protection Agency: https://www.epa.gov/warm

EPA United States Environmental Protection Agency. (2020, June 3). *Search for Superfund Sites Where You Live*. Retrieved Aug. 1, 2020, from EPA United States Environmental Protection Agency: https://www.epa.gov/superfund/search-superfund-sites-where-you-live

esa. (2020). *Algal bloom in the Baltic Sea*. Retrieved June 23, 2020, from eesa: https://earth.esa.int/web/earth-watching/environmental-hazards/content/-/article/algal-bloom-in-the-baltic-sea

ETIA ECOTECHNOLOGIES. (n.d.). *Biogreen Multipurpose pyrolysis unit for biomass and waste conversion.* Retrieved July 2, 2020, from ETIA ECOTECHNOLOGIES: file:///C:/Users/MelissaBaldridge/Downloads/Biogreen+-+technical_doc_v.2.0_compressed.pdf

ETIA SA. (n.d.). *Biogreen.* Retrieved Aug. 10, 2020, from pdf.directindustry.com: https://pdf.directindustry.com/pdf/etia/biogreen-general-documentation/58496-353595.html

eXtension. (2019, April 3). *Biochar: Prospects of Commercialization*. Retrieved May 18, 2020, from eXtension FARM ENERGY : https://farm-energy.extension.org/biochar-prospects-of-commercialization/

Free Icons Library. (n.d.). *Free Icons Library*. Retrieved Aug. 7, 2020, from Free Icons Library: https://icon-library.com/

Galinato, Suzette P.; Yoder, Jonathan K.; Granatstein, David. (2011, Aug. 5). The economic value of biochar in crop production and carbon sequestration. *Energy Policy*, 6344-6350. Retrieved May 15, 2020, from https://www.sciencedirect.com/science/article/abs/pii/S0301421511005672

GES GREEN EARTH SOLUTIONS. (n.d.). *ECO-CHARGE YOUR GROWTH*. Retrieved Aug. 12, 2020, from GES GREEN EARTH SOLUTIONS: http://ges.green/

Google. (2020). *Colorado*. Retrieved July 18, 2020, from Google Maps: https://www.google.com/maps/place/Colorado/@40.2455932,-104.9976349,10.5z/data=!4m5!3m4!1s0x874014749b1856b7:0xc75483314990a7ff!8m2!3d39.5500507!4d-105.7820674

Gounley, T. (2018, Aug. 17). *Colorado wood pellet manufacturer files for Chapter 11 bankruptcy*. Retrieved July 27, 2020, from BusinessDen: https://businessden.com/2018/08/17/colorado-wood-pellet-manufacturer-files-for-chapter-11-bankruptcy/

Grady, Deanna. (2019, April 22). *Selling Into Industries: Government*. (LinkedIn Corporation ©) Retrieved Aug. 7, 2020, from LinkedIn LEARNING: https://www.linkedin.com/learning/selling-into-industries-government/gsa-based-and-other-buying-vehicles?u=2194065

Grand View Research, Inc. (2019, April). *Biochar Market Size, Share & Trends Analysis Report by Technology (Gasification, Pyrolysis), by Application (Farming, Livestock), By Region, And Segment Forecasts, 2019-2025*. Retrieved July 31, 2020, from GRAND VIEW RESEARCH: https://www.grandviewresearch.com/industry-analysis/biochar-market

GREEN SEAL ENVIRONMENTAL, INC. (n.d.). *Construction and Demolition Waste Characterization and Market Analysis.* Retrieved May 18, 2020, from Green Seal Environmental, Inc.: https://www.gseenv.com/

Gunarathne, V., Ashiq, A., Ginige, M. P., Premarathna, S. D., de Alwis, A., Athapattu, B., & Rajapaksha, A. U. (2018). Municipal Waste Biochar for Energy and Pollution Remediation. In G. Crini, & E. Lichtfouse (Eds.), *Green Absorbents for Pollutant Removal* (p. 410). Besançon, France: Springer. Retrieved June 2, 2020, from https://link-springer-com.ezp-prod1.hul.harvard.edu/book/10.1007%2F978-3-319-92162-4

Hagemann, N., Spokas, K., Schmidt, H.-P., Kägi, R., Böhler, & Bucheli, T. D. (2018, Feb. 9). Activated Carbon, Biochar and Charcoal: Linkages and Synergies Across Pyrogenic Carbon's ABCs. *Water, 10*(182), 1-19. doi:https://doi.org/10.3390/w10020182

Hazardous Materials and Waste Management Division. (2019, Feb. 1). *FY2018 Annual Report to the Colorado General Assembly: Status of the Solid Waste Management Program in Colorado.* Retrieved Nov. 21, 2019, from Colorado Department of Public Health & Environment: file:///C:/Users/MelissaBaldridge/Downloads/Solid%20Waste%20-%20Annual%20Reports%20-

%20FY2018%20Annual%20Report%20to%20the%20Colorado%20General%20Assembly%20-%20HB%201288%20Report.PDF

Huggins, T. M., Haeger, A., Biffinger, J. C., & Ren, Z. J. (2016). *Granular Biochar Compared with Activated Carbon for Wastewater Treatment and Resource Recovery*. (ScienceDirect) Retrieved June 4, 2020, from ScienceDirect: https://www.sciencedirect.com/science/article/abs/pii/S004313541630118X?via%3Dihub

ICM, Inc. (2020). *ICM, Inc. Accelerates Innovation with ICM ELEMENT*. Retrieved July 26, 2020, from ICM: https://icminc.com/icm-inc-accelerates-innovation-with-icm-element/

Industrial Products. (n.d.). *ULTRATECH 9457 - FILTER SOCK & STORM WATTLE - SEDIMENT REMOVAL*. Retrieved Aug. 12, 2020, from Industrial Products: https://www.industrialproducts.com/ultratech-9457-filter-sock-and-storm-wattle-sediment-removal.html?gclid=CjwKCAjwps75BRAcEiwAEiACMftPLD6f0IXxF1FE4EnCY0Sg3iV0xPduyRM1RfJkvxYlibvF_vftQRoCwPUQAvD_BwE

International Biochar Initiative. (2018). *CERTIFICATION PROGRAM*. Retrieved April 17, 2020, from International Biochar Initiative: https://biochar-international.org/certification-program/

Jones, C. (2020, June 17). *Oakdale manufacturer acquires segment of Colorado firm backed by Google*. Retrieved July 27, 2020, from MINNEAPOLIS/ST. PAUL BUSINESS JOURNAL: https://www.bizjournals.com/twincities/news/2020/06/17/national-carbon-technologies-acquires-colorado.html

Joseph, S., Taylor, P., & Cowie, A. (n.d.). *BASIC PRINCIPLES AND PRACTICE OF BIOCHAR PRODUCTION AND KILN DESIGN*. Retrieved April 23, 2020, from International Biochar Initiative: https://biochar.international/guides/basic-principles-of-biochar-production/

Kelly, D. C. (2019). *How to Determine Product Market Fit in Your Industry*. (HubSpot, Inc.) Retrieved Aug. 11, 2020, from HubSpot: https://blog.hubspot.com/sales/product-market-fit

Kim, D., Anderson, N. M., & Chung, W. (2015). Financial Performance of a Mobile Pyrolysis System Used to Produce Biochar from Sawmill Residues. *FOREST PRODUCTS JOURNAL, 65*(5/6), 189-197. Retrieved July 28, 2020, from https://www.fs.fed.us/rm/pubs_journals/2015/rmrs_2015_kim_d001.pdf

Koper, T., Weisberg, P., Lennie, A., Driver, K., Simons, H., Rodriguez, M., . . . al., e. (2010). *Methodology for Biochar Projects.* Retrieved May 21, 2020, from American Carbon Registry: https://americancarbonregistry.org/carbon-accounting/standards-methodologies/methodology-for-emissions-reductions-from-biochar-projects/acr_tct_biochar-meth_public-comment-draft.pdf

Laird, D., Fleming, P., Wang, B., Horton, R., & Karlen, D. (2010, June 26). Biochar impact on nutrient leaching from a Midwestern agricultural soil. *Geoderma*, 436-442. doi:10.1016/j.geoderma.2010.05.012

Lesniewski. (2016, Oct. 1). *Colorado road map*. Retrieved Aug. 1, 2020, from depositphotos: https://depositphotos.com/125380548/stock-illustration-colorado-road-map.html

Lotus, J. (2020, March 27). *Abandoned mines in the West post safety, environmental hazards*. Retrieved June 23, 2020, from U.S. News: https://www.upi.com/Top_News/US/2020/03/27/Abandoned-mines-in-the-West-pose-safety-environmental-hazards/5351585099022/

Manning, A. (2017, Oct.). *Carbon coating gives biochar its garden-greening power*. Retrieved May 18, 2020, from COLORADO STATE UNIVERSITY | SOURCE: https://source.colostate.edu/carbon-coating-gives-biochar-garden-greening-power/

Materials Management Branch, et Al. (2017, May). *The State of the Practice of Construction and Demolition Material Recovery.* Retrieved March 5, 2020, from EPA United States Environmental Protection Agency: https://nepis.epa.gov/Exe/ZyPDF.cgi/P100SSJP.PDF?Dockey=P100SSJP.PDF

Merriam-Webster, Incorporated. (2020). *Merriam-Webster*. Retrieved July 27, 2020, from Merriam-Webster: https://www.merriam-webster.com/dictionary

Mile High Flood District. (2020). *About Us.* Retrieved July 31, 2020, from Mile High Flood District: https://mhfd.org/about/

Miller, L. (2014). *Dining in Aspen*. Retrieved June 23, 2020, from limelight: https://blog.limelighthotels.com/colorado-foods-sweet-in-summertime/

Moor, C. (2018, Nov. 28). *Crossing the Chasm: A Closer Look at Disruptive Technology in Construction*. Retrieved Aug. 4, 2020, from CE CONSTRUCTION EXECUTIVE: https://constructionexec.com/article/crossing-the-chasm-a-closer-look-at-disruptive-technology-in-construction

NAICS Association. (2018). *Welcome to NAICS Association*. Retrieved Aug. 7, 2020, from NAICS ASSOCIATION: https://www.naics.com/

OMRI. (2020). *Welcome to the Organic Materials Review Institute*. Retrieved Aug. 12, 2020, from OMRI: https://www.omri.org/

Pepperl+Fuchs. (2020). *Water Inlet in Wastewater Treatment Plants*. Retrieved June 23, 2020, from PEPPERL+FUCHS: https://www.pepperl-fuchs.com/global/en/33441.htm

Perez-Mercado, L. F., Lalander, C., Berger, C., & Dalahmeh, S. S. (2018, Dec. 12). Potential of Biochar Filters for Onsite Wastewater Treatment: Effects of Biochar Type, Physical Properties and Operating Conditions. *Water, 10*(1835), 1-18. doi:10.3390/w10121835

Popper, B. (2014, April 14). *The inventor of everything*. Retrieved July 27, 2020, from THE VERGE: https://www.theverge.com/2014/4/14/5561250/cool-planet

Pourhashem, G., Hung, S. Y., Medlock, K. B., & Masiello, C. A. (2018, Dec. 21). Policy support for biochar: Review and Recommendations. *GCB - BIOENERGY, 11*, 364-380. doi:https://doi.org/10.1111/gcbb.12582

Pranitha, S. (2017, Dec. 8). *Biochar*. Retrieved June 17, 2020, from About Project Drawdown: https://drawdowniitkgp.wordpress.com/2017/12/08/biochar/

Project Drawdown. (2020). *BIOCHAR PRODUCTION*. Retrieved Aug. 11, 2020, from PROJECT DRAWDOWN: https://drawdown.org/solutions/biochar-production

puro.earth. (2019, Dec. 6). *puro CO2 Removal Marketplace GENERAL RULES.* Retrieved June 24, 2020, from Why Puro.earth: https://static.puro.earth/live/uploads/tinymce/Puro_Documents/Puro-Rules-Methodologies_v1_3_Published_06_Dec_2019.pdf

puro.earth. (n.d.). *CARBON TRANSFORMATION STARTS HERE*. Retrieved June 16, 2020, from puro.earth: https://puro.earth/

Ramlow, M., & Cotrufo, M. F. (2017). Woody biochar's greenhouse gas mitigation potential across fertilized and unfertilized agricultural soils and soil moisture regimes. *GLOBAL CHANGE BIOENERGY*, 1-15. doi:10.1111/gcbb.12474

Ramlow, M., Foster, E., Del Grosso, S., & Cotrufo, M. (2019). Broadcast woody biochar provides limited benefits to deficit irrigation maize in Colorado. *Agriculture, Ecosystems and Environment, 269*, 71-81. doi:https://doi.org/10.1016/.agee.2018.09.017

Ramlow, M., Keske, C., & Cotrufo, M. (2016, Jan.). *Biochar in Colorado - 0.509.* Retrieved May 18, 2020, from COLORADO STATE UNIVERSITY EXTENSION: https://extension.colostate.edu/docs/pubs/crops/00509.pdf

Redling, A. (2020, May 26). *Inside DTG Recycle's C&D operations*. Retrieved June 9, 2020, from CONSTRUCTION & DEMOLITION RECYCLING: https://www.cdrecycler.com/article/dtg-recycle-tom-vaughn/

Romeo, J. (2020, Jan. 30). *Beetle infestation slows in Southwest Colorado, but only for lack of trees*. Retrieved Aug. 4, 2020, from THE Durango HERALD: https://durangoherald.com/articles/312513#:~:text=In%20Southwest%20Colorado%2C%20the%20spruce,Pass%20in%20the%20late%201990s.&text=In%202019%2C%20flights%20over%20the,discovered%20areas%20of%20beetle%20spread.

Romig, S. (2017, Aug. 22). *Biochar industry grows as new uses identified*. Retrieved July 26, 2020, from coloradobiz: https://www.cobizmag.com/biochar-industry-grows-as-new-uses-identified/

Schmidt, H. P., Bucheli, T., Kammann, C., Glaser, B., Abiven, S., Leifeld, J., & Hagemann, N. (2020, June 1). *Guidelines European Biochar Certificate for a sustainable production of biochar.* Retrieved July 26, 2020, from EBC - European Biochar Certification: https://www.european-biochar.org/en/ct/2-EBC-guidelines-%26-documents-for-the-certification

Schmidt, H.-P., & Wilson, K. (Switzerland, May 12). The 55 uses of biochar. *the Biochar Journal*, 2014. Retrieved July 17, 2020, from https://www.biochar-journal.org/en/ct/2

SPEC-NET™ PTY LTD. (2017). *Custom Culvert Grates and Screens from EJ Australia*. (SPEC-NET™ PTY LTD) Retrieved Aug. 9, 2020, from SPEC-NET News Lounge: https://www.spec-net.com.au/press/0514/eja_280514/Custom-Culvert-Grates-and-Screens-EJ-Australia

Stamberger, J. (2018, March 20). *4 HEALTHY AND GREEN USES FOR CANNABIS LEAVES*. Retrieved Aug. 5, 2020, from MEDICAL MARIJUANA, INC.: https://www.medicalmarijuanainc.com/cannabis-leaves-and-their-uses/

Stockholm Resilience Centre. (2015). *The nine planetary boundaries*. Retrieved May 9, 2019, from Stockholm Resilience Centre: https://www.stockholmresilience.org/research/planetary-boundaries/planetary-boundaries/about-the-research/the-nine-planetary-boundaries.html

The AMERICAN SOUTHWEST. (n.d.). *Colorado Map*. Retrieved July 8, 2020, from The AMERICAN SOUTHWEST : https://www.americansouthwest.net/colorado/map.html

The Climate Registry. (2018, April 19). *Climate Registry Default Emission Factors.* Retrieved March 8, 2019, from The Climate Registry: https://www.theclimateregistry.org/wp-content/uploads/2014/11/2016-Climate-Registry-Default-Emission-Factors.pdf

The Colorado Chapter of the American Society of Landscape Architects. (2020). *ASLA COLORADO*. (The Colorado Chapter of the American Society of Landscape Architects) Retrieved Aug. 11, 2020, from ASLA COLORADO: https://www.aslacolorado.org/

The Town of Amherst. (n.d.). *Stormwater Management*. Retrieved July 18, 2020, from Amherst Massachusetts: https://www.amherstma.gov/3500/Stormwater

Tigercat International Inc. (2020). *6050 Carbonator.* Retrieved July 26, 2020, from Tigercat: https://www.tigercat.com/product/6050-carbonator/

U.S. Department of the Interior. (n.d.). *Mineral Resource Data System by common geographic areas*. Retrieved Aug. 1, 2020, from USGS science for a changing world: https://mrdata.usgs.gov/mrds/geo-inventory.php

U.S. Forest Service. (2018, Aug. 16). *Survey and Analysis of the US Biochar Industry Preliminary Report Draft: August 16, 2018.* Retrieved April 16, 2020, from USBI: https://biochar-us.org/sites/default/files/news-files/Preliminary%20Biochar%20Industry%20Report%2008162018_0.pdf

United Nations | Department of Economic and Social Affairs Sustainable Development. (n.d.). *THE 17 GOALS*. (United Nations) Retrieved Aug. 11, 2020, from United Nations : https://sdgs.un.org/goals

United Nations Development Programme. (2020). *SUSTAINABLE DEVELOPMENT GOALS Background on the goals*. Retrieved Aug. 11, 2020, from United Nations Development Programme: https://www.undp.org/content/undp/en/home/sustainable-development-goals/background.html

UNITED NATIONS. (n.d.). *SUSTAINABLE DEVELOPMENT GOALS Communications Materials*. Retrieved Aug. 11, 2020, from SUSTAINABLE DEVELOPMENT GOALS: https://www.un.org/sustainabledevelopment/news/communications-material/

Urban Drainage and Flood Control District. (2010, Nov.). *URBAN STORM DRAINAGE VOLUME 3.* Retrieved Aug. 2, 2020, from MHFD MILE HIGH FLOOD DISTRICT: https://mhfd.org/wp-content/uploads/2019/12/01_USDCM-Volume-3.pdf

USDA United States Department of Agriculture. (n.d.). *BioPreferred*. Retrieved April 17, 2020, from USDA United States Department of Agriculture: https://www.biopreferred.gov/BioPreferred/

VadimPP. (2009, Dec. 21). *Texture of ripple on river surface - stock image*. Retrieved Aug. 4, 2020, from depositphotos: https://depositphotos.com/1453022/stock-photo-texture-of-ripple-on-river.html

Watson & Associates, LLC. (n.d.). *Limited Liability Company LLC Advantages and Disadvantages*. Retrieved July 27, 2020, from Watson & Associates LLC: https://blog.theodorewatson.com/advantages-disadvantages-limited-liability-company/

WIKIMEDIA COMMONS. (2016, June 10). *File:Golden Wheat Field.jpg*. Retrieved Aug. 1, 2020, from WIKIMEDIA COMMONS: https://commons.wikimedia.org/wiki/File:Golden_Wheat_Field.jpg

Wright Water Engineers, Inc. (2019, April). *BIG DRY CREEK ANNUAL WATER QUALITY SUMMARY FOR 2018.* Retrieved July 31, 2020, from Big Dry Creek Watershed Association: https://static1.squarespace.com/static/5e56e4bb1fb797198395d9a5/t/5ec6dd924091df130b2f2c8f/1590091162769/2019BigDryCreekAnnualReport.pdf

WRT Western Renewable Technologies. (n.d.). *Western Renewable Tecnologies.* Retrieved April 16, 2020, from Pacific Region Bioenergy Partnership: http://www.pacificbiomass.org/documents/WRT.pdf

www.CoolTerra.com. (2018, Oct. 30). *Cool Planet: Cool Terra Organic*. Retrieved Aug. 7, 2020, from LANDSCAPE MANAGEMENT: https://www.landscapemanagement.net/cool-planet-cool-terra-organic/

Xcel Energy, Inc. (2020, Jan. 1). *COLORADO COMMERCIAL AND INDUSTRIAL GAS AND ELECTRIC RATE SCHEDULE SUMMARIES.* Retrieved July 30, 2020, from Xcel Energy : https://www.xcelenergy.com/staticfiles/xe/Regulatory/COBusRates.pdf

Zeringue, J. (2019, Oct. 22). *New forest product making soils better*. Retrieved July 27, 2020, from LOUISIANA FORESTRY ASSOCIATION: https://www.laforestry.com/post/2019/10/22/new-forest-product-making-soils-better

APPENDIX A

Metro Biochar®

Project Roadmap & Milestones, 2020-2021

Q4 — **FY 2020** — PHASE 1

REAL ESTATE & FIXED ASSETS

- Engineer vets APEN permit (done Oct. 31st)
- Submit APEN permit to CDPHE for approval (done Oct. 31st)
- Site real estate decisions made
- Site MRF equipment decisions made
- CAPEX & OPEX models done for other pyrolizer systems
- Explore waste-heat options with Xcel Energy, Inc., et Al.

MARKET, RESEARCH & TECHNICAL/USE SPECIFICATIONS DEVELOPMENT

- Find biochar pilot partners, move SW research forward
- Find filtration manufacturer partners, move SW/WW research forward
- Find *Cannabis* research market partners, move AG research forward
- Develop & vet Company definition of “clean” wood with implementation guide-lines
- Revise carbon (D) pricing model for \$/ton CO_2 and breakeven price for Eastern Plains crops

SALES & MARKETING

- Populate CRM
- Find buyers in new markets
    - MR and cleanup
    - Dairy operations
    - Oil and gas

Q1 — **FY 2021**

MARKET, RESEARCH & TECHNICAL/USE SPECIFICATIONS DEVELOPMENT

- Begin certification applications (IBI, OMRI, USDA, etc.)

SALES & MARKETING

- Begin Company branding
    - Market Biochar® branding
    - Set up website
    - Start email drip marketing with research & industry news

Q2 — **FY 2021** — PHASE 2

REAL ESTATE & FIXED ASSETS

- Receive APEN permit from CDPHE (May 31st)

Q3 — **FY 2021**

PRODUCTION

- Begin first production

APPENDIX B

Survey and Analysis of the US Biochar Industry

Preliminary Report Draft; August 16, 2018

,WERC project MN17-DG-230

Executive Summary

A survey and analysis of the US biochar industry was commissioned by the US Forest Service, via a Wood Innovations Grant. Two surveys were generated; one for producers and one for users. The Surveys were composed using Survey Monkey and the US Biochar Initiative distributed invitations and follow-up requests. Out of an estimated 135 biochar producers in the US, responses were received from 61, a 45% response rate; 58 responses from domestic biochar users were received.

The surveys are complementary in their results with two trends standing out:

- Growth in sales supported by a general optimism in the strength of the marketplace.
- Desire for more information and support from all types of resource entities.

The producer survey indicated the expected growth in year-to-year production is supported by the expectation of increased sales, higher prices, and the availability of feedstocks at affordable prices. This outlook is also bolstered by the expectation of users to increase purchases.

The users survey provided a snapshot of an optimistic marketplace. Many of the smaller users left comments expressing their interest in learning more about biochar, about the broader marketplace, about how to market more effectively to grow their businesses, and for more in-depth information about research results (which could help both their understanding and marketing.) They also uniformly anticipated higher sales.

Responses to questions about what the industry/trade association, public policy, and the USFS specifically can do to support and grow the market provided particular insight. The most often cited historic support come from IBI and USFS Wood Innovation Grants. Cooperative research initiatives with universities were noted by larger producers as helping to advance their progress while there was widespread desire for more biochar-related research.

From a policy standpoint, producers cited recognizing biochar as carbon negative (and getting some financial credit for it) by almost 25% of the respondents. The second most repeated support need was to certify biochar as an animal feed supplement—by six of the responding 23 larger producers—and both USDA and FDA were cited as important players in opening that market. It was noted by a number of respondents that biochar as a feed supplement is allowed in Europe already.

Both users and producers see the need for much higher profile education efforts—in support of biochar as a desirable and sought after product. The new market segment of biochar as an animal feed supplement is considered strongly for its potential to have a significant impact on both producers and resellers; however resellers will likely see less effect since volume sales seem to be provided mostly from producers. More information on this market (current European experience, domestic customer interest, price points, and value added opportunities) is needed to better predict how significant the animal feed supplement could be. The same can be said for other currently minor segments with large potential markets: stormwater filtration, mine reclamation, and odor control.

Introduction:

A survey and analysis of the US biochar industry was commissioned by the US Forest Service, via a Wood Innovations Grant in 2017. The survey was conducted by the project team consisting of:

- Kathleen Draper, Finger Lakes Biochar and Ithaka Journal; NY
- Harry Groot, Dovetail Partners, Inc.; Minneapolis MN
- Tom Miles, Tom Miles Consulting, Inc. and US Biochar Initiative; Portland, OR
- Martin Twer, Biomass Program Director, The Watershed Research & Training Center; Hayfork, CA

Methodology

Two surveys were conducted; one for producers and one for users. The Survey was composed using Survey Monkey and the US Biochar Initiative mailed the invitations and follow-up requests. The specific survey input was promised as confidential, however a field was provided to allow individuals to authorize follow-up—which was conducted with selected respondents by project team members.

Out of an estimated 135 biochar producers in the US, we received responses from 61, a 45% response rate, as well as 58 responses from domestic biochar users in a parallel survey. The analysis was based on these responses (survey questions attached in Appendix A and B) in addition to follow-up interviews by phone and in person.

All members of the project team participated in the data compilation, analysis, and reporting. Of the 69 responding producers, 7 respondents were Canadian and one was German. Their data has been segregated. All 58 of the users were domestic.

Note on data management:
Some of the data presented will be based on the entire response set; however, the focus will be mainly on the higher volume producers and users since the project team feels they reflect "the industry" most accurately. The smaller producers and users are frequently do it yourselfers (DIY) and skew the desired industry focus of this study.

The raw response data is not being shared to honor the promise of confidentiality to respondents.

Introduction

Prior to this survey, the US biochar industry production was estimated to be between 15,000-20,000 tons per year (TPY). This survey provides data to support an estimate of 35,000 to 70,000 TPY. Given that this estimate is based on a 45% response rate, it's reasonable to project an industry-wide production of 45,000 TPY, which is the basis used in this report.

Using a 75% reduction in dry weight from raw feedstock to finished biochar, biochar production would consume about 200,000 bone dry tons of biomass as feedstock. Knowing that most feedstock ranges from 20 to 60% moisture content (for woody and ag biomass, the most common feedstocks) it can be extrapolated that the industry uses between 125,000 to 250,000 delivered tons of feedstock.

The users represent a usage of 163 to 200+TPY, less than 1% of industry's projected production capacity. There is no way to know what percentage of all consumers this represents, but the project team solicited their input to better understand issues rather than to gain a comprehensive picture of market demand.

Producers Survey Data

5 producers over 5000 Tons per year of biochar production (TPY)
7 between 1000 and 5000 TPY (with one being Canadian)
5 between 500 and 1000 (with one being Canadian)
6 between 100 and 500 (with one being Canadian)
1 between 50 and 100, and 45 respondents producing less than 50 Tons per year (with 4 Canadian and 1 German.) 21 respondents didn't state their production volume.

The domestic biochar production represented by the survey respondents is between 35,000 and 70,000 Tons per year. The Canadian production adds an additional 1,700 to 6,600 TPY for a North American total of 18,700 to 76,600 TPY.

A note about the following data presentation: The larger producers were relatively thorough in responding to the survey questions, so while there is a fairly consistent 25 to 30% non-response rate on a question-by-question basis, it affects the lower 10 to 20% of the volume of biochar produced for the most part. As a result, this analysis will focus large on the volume producers.

The larger producers have been in business on average, longer than most of the intermediate sized producers, however there were 9 firms producing less than 100 TPY with more than 5 years production experience.

57% of the respondents were biochar producers primarily, with 29% as a byproduct of energy generation and 8% as a byproduct of electricity generation. For 6%, biochar production was a form of waste disposal. 29% didn't respond to this question.

82% of the respondents were producers and only 18% were resellers. Of the 14 resellers, only two purchased between 1000 and 5000 tons per year while 4 purchased between 100 and 500 Tons, and 8 purchased less than 50 Tons per Year.

Producers sell most of their biochar for agricultural uses: gardens, field crops, orchards, horticultural applications, turf, and landscaping. The table below shows for which applications producers and resellers are selling biochar:

The highlighted uses below are aggregated under an "Agricultural" class:

Garden	62%
Horticulture, specialty crops	47%
Field Crops	42%

Orchard or tree crops	29%
Turf	20%
Landscaping	36%
Stormwater, filtration	33%
Odor control	27%
Other	18%

The "other" category includes concrete admixture and pigments.

Of the largest volume producers (23 in number), 43% (10) make biochar for no specific end use. 35% (9) make biochar for agricultural applications specifically, 9% (2) for drainage, 13% (3) for odor control specifically, and 22% (5) didn't say.

Five of the largest volume producers sell their biochar as-is. Twelve of them process further (sizing, pelletizing, charging/inoculating/activating, neutralizing pH, and/or mixing with other soil amendments), and 5 didn't answer.

Biochar is supplied as (in rank order):

1. Coarse chips
2. Fine powder
3. Fine screened chips
4. Pellets
5. Granules or prills
6. Liquid suspension.

Most of the large suppliers responding (39%, 9) do not pursue any independent certification, however 5 have OMRI listing or Organic certification and 5 use IBI standards. Nine of the 23 did not respond.

The majority of biochar is shipped locally and regionally (less than 500 miles), however exports are being made to Europe, Asia, Australia and the Middle East by producers in all production classes.

Responding producers and resellers were evenly split on customer requests to know if the biochar was locally sourced, with the smaller scale producers most often asked.

Most all producers provide information to customers about their biochar—from analysis results to how-to-use instructions. Only 1 of the large volume producers provided no information, with five not responding.

None of the biochar producers—of any size—expect there to be a decrease in demand, with almost 60% of respondents expecting prices to increase more than 10% as a result of that demand. Most of the larger tier producers expect demand to grow modestly to significantly. Only 4 of the 23 upper tier producers anticipate needing to expand capacity to meet growing demand and only three of them expect to have a problem obtaining feedstock. The feedstock sourcing is predominantly woody in nature, but a wide variety of materials are viewed as potential sources, including manures, grasses, ag waste, construction waste, fiber, and food waste.

The market segments showing the highest expectations for growth are, in rank order: crops, filtration, odor control and other, with biochar as an animal feed supplement the most mentioned market segment.

Advertising biochar was direct, relatively traditional, and unsophisticated:

Word of mouth	68%
Direct response to inquiries	46%
Google Adwords	2%
Print media	10%
Website and other electronic media	44%
Conference and trade show displays	29%

The top producers claim to have spent millions on research annually, with the level of support declining proportionately as production levels decreased. The degree of decrease was not linear; however without more specific details the relative percentages and trends cannot be determined.

The data last section asked open ended questions about policy and opportunities for support provided wide ranging responses. There were many thoughtful suggestions and a few common threads, which will be captured and discussed in the analysis section.

Users Survey Data

The breakdown of users was:
5 users consuming more than 20 Tons per year of biochar (TPY)
10 users consuming between 5 and 20 TPY
11 users consuming less than 1 TPY
25 users consuming a few gallons per year (at 7.5#/gal.)
6 users didn't specify quantity.

As noted above, the users represent less than 1% of the estimated domestic production of biochar.

Most respondents classified themselves as gardeners, farmers or landscape contractors. In the larger users, most were resellers. The motivation for using biochar was fairly consistent and multi-faceted, including: modifying soil texture, improving air/water porosity, improving water management, and increasing soil carbon. There was modest motivation to change soil chemistry or modify pH, and to improve disease resistance.

The majority of respondents (55%) use the biochar dry. 38% use it inoculated and 39% blend it, most commonly with soil and/or other soil amendments.

The biochar users bought the material in the following forms (in rank order) :

1. Fine powder
2. Fine screened chips

3. Coarse chips
4. Pellets
5. Granules or prills
6. Liquid suspension

As seems reasonable, larger volume users have been in business longer than smaller users, however 49% of all respondents have been using biochar for at least two years and most of the top tier have over 5 years' experience.

Of the 54 respondents, there was a notable increase in current volume used versus expectations for the coming year:

Usage	Last Year	This Year
Less than a ton	49%	28%
More than a Ton	23%	31%
A Semi-Truckload (20T)	19%	26%
Multiple Truckloads	9%	15%

There seems to be broad satisfaction with suppliers in that 81% of users have not changed from whim they buy; 10% had changed suppliers due to quality issues and 8% due to availability issues.

Organic/OMRI Certification was important to 31% of respondents; IBI to 9%; State-level certification to 15%; and no certification was noted as important by 36%. 92% of respondents said the climate impact of biochar was of importance to them. Only 4 of the 26 upper tier producers (15%)said climate impact was unimportant.

Most top tier users get their supply from 100 to 500 mile shipping distance, but 27% of them experience shipping distances of over 1500 miles. With few exceptions, respondents indicated the fact the biochar is produced locally was an important criteria (94%).

When asked whether they knew or cared from what or how their biochar was made only one respondent answered "no." Four percent said that information was not disclosed and 85% said they knew the details despite responses to a question about receiving an analysis where 43% responded yes. All the recurrent large volume buyers received analyses of their biochar while only 40% of the truckload volume buyers received analyses.

Reported prices paid for biochar ranged widely depending on the packaging and volume purchased. For the larger scale users the lowest cited cost was $75/CY, the average price was $129/CY, with $200/CY FOB the most often cited price[1] (or $1600/Ton.)

As with the Producers, the input offered from open ended questions will be discussed in the analysis section.

[1] Conversions used: 8CY/ton or 216 CF/ton; 9.25#/CF; 1CY = ~22gallon

Analysis of Producers Survey Data

Two trends stand out: the growth in production and general optimism about the strength of the marketplace. Secondly, is desire for more information and support from all resource providers.

The growth in year-to-year production is supported by the expectation of lower prices and the potential availability of feedstocks at affordable prices. This outlook is also bolstered by the expectation of users to increase purchases.

Responses to questions about how the industry/trade association, public policy, and the USFS specifically can do to support and grow the market provided particular insight. The most often cited historic support come from IBI and USFS Wood Innovation Grants. Cooperative research initiatives with universities were noted by larger producers as helping to advance their progress.

From a policy standpoint, recognizing biochar as carbon negative (and getting some financial credit for it) was mentioned by almost 25% of the respondents. The second most repeated support need was to certify biochar as an animal feed supplement—by six of the larger producers—and both USDA and FDA were cited as important players in opening that market. It was noted by a number of respondents that biochar as a feed supplement is allowed in Europe already.

There was frustration expressed with EPA regulations by two mid-sized operations, but no specifics were provided as to what actions would help ease their concern.

A number of producers noted the need for stronger definition of biochar "grades" and improved standards. Others made mention of the desire for more support to get the word out to users (the public and farmers specifically) about the benefits of biochar.

Responses to a question about how USBI or a trade association could best support producers were very similar to the question about what policy initiatives would help most: advocacy for carbon credits, education of the public and farmers specifically, marketing, and research leadership.

Two notable actions were suggested for USBI. The first is to participate more in long-term research which (hopefully) shows the benefits of biochar in soil and mixed amendment systems. The second notable suggestion was for market research which "compares biochar to existing products (like AC, compost, and soil blends) to determine price points and pain points of buyers that use other [soil amendment] products.

In response to a question how the USFS and Federal Agencies could support the biochar industry a number of responses cited purchasing biochar for forest and mine reclamation. Improved accessibility to, and the increased use of stewardship contracts to provide feedstock was mentioned by a number of producers while compliments were given to USFS for the use of stewardship contracts by other producers. Streamlined regulations to acquire woody biomass were mentioned by multiple respondents. One insightful respondent suggested a cost/benefit analysis: "Quantify in $ terms the benefits of avoided slash piling burning, irrigation water availability from juniper treatments and thinning." As well as "Economic and enterprise models that help build an investment case for biochar production."

One interesting response was the amount spent on research internally. Three of the five largest firms claim to be spending in excess of $1M/year, with and 2 currently mid-sized operations spending similarly, and four others in the $250K to $500K range. These commitments are impressive and, for a relatively young industry with a relatively small market, can be interpreted as indicative of optimism for stronger demand for biochar products.

Analysis of Users Survey Data

The users survey provided a snapshot of an optimistic marketplace. Many of the smaller users left comments expressing their interest in learning more about biochar, about the broader marketplace, about how to market more effectively to grow their businesses, and for more in-depth information about research results (which could help their understanding and marketing.)

One respondent expressed interest in using biochar as a concrete additive and as a component in other building materials (unspecified) which is being done by one of the large producers, suggesting a potential for collaboration.

Shipping and handling costs were cited by a two users as being of more concern than the raw biochar costs even though their shipping distance was less than 500 miles for truckload volumes.

As in the producers' survey responses, users wanted more information about the animal feed and stormwater filtration markets.

Conclusions and Next Steps

The surveys are complementary in their results. Both producers and users see a growing demand. There are different expectations in price points between the two groups, which is typical and will be worked out over time as production is balanced with usage.

Both groups see the need for much higher profile education—in support of biochar as a desirable and sought after product. The new market segment of biochar as an animal feed supplement is considered strongly and its potential could have a significant impact on both producers and resellers, however resellers will likely see less as volume sales seem to be provided mostly from producers. A value added opportunity may exist for resellers to produce a branded or customized end-product, which producers could be reluctant to take on. More information on this market (current European experience, domestic customer interest, price points, value added opportunities) are needed to better predict how significant it could be.

There was a difference between the form of the biochar being provided by producers and the form being purchased by the users. This may be useful to producers in aligning better with buyers of their finished product. Future research should explore this facet more closely.

Biochar as a confirmed carbon sequestering product was expected to have the greatest potential to enhance its demand. However, it's an unlikely driver in the near term without a solid scientific claim (and/or legislation.) There are a wide variety of production technologies and, therefore, a wide range of carbon balances to consider. This variability complicates the certification of carbon sequestration capability and considerable collaboration, funding, and effort will be necessary to establish a credible calculation schema. Political considerations also come into play considerably in this process as there are already a number of skeptical organizations actively questioning the entire system of woody biomass production and conversion. Collaborating in the biomass energy producer's efforts to quell and quantify could be a cost effective strategy.

For updated information on this project check the USBI website: http://biochar-us.org/news/us-biochar-market-survey-0.

And for information on this project and other explorations of our land use decisions, visit the Dovetail Partners Report website: http://www.dovetailinc.org/reports.

The work upon which this project is based was funded in whole or in part through a grant awarded by the U.S. Forest Service, Wood Innovations; (#17-DG-11420004-230 WERC).

Appendix C, i

SWOT ANALYSIS

Biochar Now, Berthoud, CO

STRENGTHS

- In business since 2011.[1]
- MASSIVE operation (17 kilns).[2]
- Large capacity (CDPHE air permit for up to 70 kilns. He has 17 in operation.)[3]
- Expert in field
- Industry insiders give owner James Gaspard grudging respect.[4]
- Varied buyers – high-value crops in California, carbon as strengthening agent in plastic (graphene), works with Interface for carbon-negative carpet tiles.[5]

WEAKNESSES

- Most expensive char available ($2,000/ton).[6]
- Not easy to reach – 40 miles from central Denver and 31 from Boulder. Traffic can render a one-way trip 1 – 1.5 hours.
- Sources wood as far away as Oregon.[7]
- Wood supply-constrained.[8]
- BN pays for feedstock ($60/ton for logs).[9]
- BN at NOx cap per the CDPHE (@35 tons, must be <40 total).[10]
- BN uses *slow* pyrolysis.[11] Would faster be better?

OPPORTUNITIES

- 5280 Recycling can partner or JV in some fashion.
- Far enough from Denver to necessitate transportation cost concern.
- BN uses propane. Expensive.[12]
- Carbon exchanges require ***no fossil fuels*** in making of biochar.[13] BN is misrepresenting its process.
- Will Cool Terra ® squeeze him?
- BN claims to have high-quality biochar. Says who? Prove it.

THREATS

- He is the largest biochar producer in the state and in proximity to Denver, 5280 Recycling Solutions' territory.
- If BN ever priced competitively ($500 - $1,000/ton or less), he would be hard to beat.
- If BN ever opted to gain further economies of scale with larger kilns, it could be hard to beat.
- He claims to have worked with stormwater entities.[13]

Template by TemplateLabs, TemplateLab.com/swot-analysis-templates

1 (Colorado Secretary of State, 2020) 2,3,5,6,7,8,12 (James Gaspard, personal communication & site visit, May 28, 2020) 4 (Ron Larson, personal communication, July 13, 2020) 10,13 (James Gaspard, personal communication & site visit, July 16, 2020) 11 (Hagemann, et al., 2018, p. 22) 13 (Schmidt, et al., 2020)

Appendix C, ii

SWOT ANALYSIS

Confluence Energy, Kremmling, CO

STRENGTHS

- Biochar Solutions owner Jonah Levine is involved with sales and other roles with them.[1]
- They have a *range* of products for industrial uses.[2]
- 2019 revenue $4 MM.[3]
- Manufacture where real estate is cheap – Kremmling and Walden.

WEAKNESSES

- They see appear to sell to a mountain community/ag market, and not urban except for retail products (TruChar).[4]
- Declared bankruptcy in 2018 due to downturn in oil and gas prices. Sold in 2019.[5,6]

OPPORTUNITIES

- They apparently sell to the mountain communities/ag and not urban.[7]
- They advertise "site reclamation" but do not have any products yet. "Coming soon."[8]
- 'Same with "air & water filtration," "erosion control," and "bio-remediation."[9]
- Are they diversifying too much? Too many products? Biochar is one among many.

THREATS

- Two production facilities – Kremmling and Walden (100-acre site, 15,000 SF bldg.)[10]
- ***Industrial users*** – oil and gas, water filtration, mine reclamation and cleanup.[11]
- Jonah Levine has been in the business awhile and sells for Confluence. He is a plodder.[12]
- They have a *range* of branded products for industrial and home uses.[13]
- Capacity to make 56,000 tons of pellets.

Template by TemplateLabs, TemplateLab.com/swot-analysis-templates

1,2,4,7,8,9,11,12,13 (confluence energy, 2020) 5 (Gounley, 2018) 3,6,10,14 (BBI International, 2019)

Appendix C, iii

SWOT ANALYSIS

Biochar Solutions, Carbondale, CO

STRENGTHS

- Owner Jonah Levine recognized as a leading biochar expert.[1]
- Distributed network and varied income streams – biochar (including private label), equipment & consulting.[2]
- Near wood source (White River National Forest).
- Slightly closer to California if he sells char there.
- In SW Colorado where spruce beetle is decimating forests.

WEAKNESSES

- Remote – not near anything (173 miles to Denver and 382 to Salt Lake City).
- He has to pay for feedstock or fetch it himself.
- Doesn't operate at the scale of Biochar Now. Relies on distributed network.[3]
- His carbonizers burn 0.5 tons of biomass.[4]

OPPORTUNITIES

- Working with BS|C might make more financial sense than with Biochar Now. Explore as soon as possible.
- Levine also sells for Confluence Energy. Who gets more of his time?

THREATS

- BS|C was started by a predecessor in 2011, and owner Jonah Levine is recognized. If he chose to expand into C&D, however unlikely, he would get off to a fast start.[5]

Template by TemplateLabs, TemplateLab.com/swot-analysis-templates

1,4 (Tom Miles, personal communication, July 6, 2020) 2,3 (BIOCHAR SOLUTIONS, n.d.) 5 (Colorado Secretary of State, 2020)

Appendix C, iv

SWOT ANALYSIS

National Carbon Technologies (formerly Cool Planet & Cool Terra® biochar)

STRENGTHS

- National Carbon Technologies bought the failed company.[1]
- Michigan facility can convert 300,000 tons biomass into biocarbon per year.[2]

WEAKNESSES

- Cool Planet's top focus was on "cheap fuel that reverses global warming."[3]
- Their environmental claims were not peer-reviewed or credible.[4]
- NCT's Louisiana factory requires 2.7 tonnes of feedstock per hour (25,000 tonnes annually).[5]
- Unclear what will happen to Denver office and plant.

OPPORTUNITIES

- Carbon sequestration/circular economic benefits should be marketed, just not upfront.
- A lower-priced biochar will be competitive.
- Cool Terra-branded biochar doesn't bridge the biochar information gap. It's unclear what the product is.

THREATS

- Setting up a large manufactory in Louisiana set to open Q4 2020.[6]
- HUGE investment – Google, BP, GE, Conoco Phillips, & NRG Energy (Cool Planet). Then bought by NCT.[6]
- NCT can produce Cool Planet's biochar more cheaply with economies of scale.[7]
- Though tweets are irregular, Twitter feed mentions industrial hemp market a lot.

Template by TemplateLabs, TemplateLab.com/swot-analysis-templates

1 (Jones, 2020) 2,5,6 (Zeringue, 2019) 3,4,6 (Popper, 2014) 7 (Chaurasia, 2020)

SWOT ANALYSIS

Colorado Biochar Resources, Pueblo, CO

STRENGTHS

- In business since 2011[1]
- Near growing *Cannabis* and/or hemp grow-house business in Pueblo (a high-value crop)
- Woman-owned business, head of line with .gov and some .com contracts[2]
- Family-run logging & pallet business moved into biochar production.[3]
- Expanded into biochar production to clean up forest-burned areas in southern Colorado.[4]
- Builds & sells kilns.[5]

WEAKNESSES

- They must pay for feedstock or fetch it themselves
- Not near forested areas
- Not near metro Denver

OPPORTUNITIES

- Out of metro Denver area
- Is CBR selling to *Cannabis* and/or hemp grow houses?

THREATS

- Only biochar maker in Pueblo, a hub for *Cannabis* grow houses.
- One of Biochar Solutions' distributed network of providers
- In big .gov or .com contracts, CBR will have the edge because it's woman-owned.

Template by TemplateLabs, TemplateLab.com/swot-analysis-templates

1 (Colorado Secretary of State, 2020) 2,3,4,5 (Romig, 2017)

Appendix C, vi

SWOT ANALYSIS
Pagosa Forest Products, LLC
Pagosa Springs, Colo.

STRENGTHS

- Using ICM ELEMENT, a gasifier with biochar as a byproduct. (Turning slash into syngas.)[1]
- At base of Rio Grande & San Juan Forests with big spruce beetle-kill.
- Owner J.R. Ford, with multiple streams of business, has been at this a long time.[2]
- Ford does not travel far for his feedstock, <35 miles.[3]

WEAKNESSES

- ICM looks to be a big, expensive bioreactor.[4]
- PFP's focus has always been on being an energy provider with biochar a second-tier product.[5]
- PFP's sells equipment, clears forests, produces energy and biochar – lots of lines of revenue *and* focus required.
- Ford's dream is to build 5MW power plant using woody biomass.[6]

OPPORTUNITIES

- PFP sells equipment, clears forests, produces energy and biochar – lots of lines of revenue *and* focus required.

THREATS

- PFP could also be a biochar supplier for the Pueblo grow-house hub

Template by TemplateLabs, TemplateLab.com/swot-analysis-template

1 (COLORADO Department of Public Health & Environment, n.d.) 2,3,5,6 (Coyner, 2015) 4 (ICM, Inc., 2020)

SWOT ANALYSIS

Tigercat 6050

STRENGTHS

- Easy to use – load and burn.
- Mobile, can be easilytransported to job sites.
- Solves a *waste* problem, reduces volume of waste by 90 percent.[1]

WEAKNESSES

- Biochar yields are *really* low – 5% compared to 25-30% for Biochar Now's kiln yields.[2]
- Technically, Tigercat is not producing biochar (open-air).
- In states where air-emissions permits are required, Tiger Cats must also get air permit.[3]

OPPORTUNITIES

- Not a biochar-creating process.[4]
- Tiger Cat is a tool for a different market looking for volumetric reduction to reduce tipping fees (e.g., arborists) or provide biochar for their horticultural clients.[5]
- Arborists could be a source of woody biomass feedstock and thus, biochar, if they do not want to buy the Tigercat, especially in states requiring air permits.

THREATS

- Easier, mobile setup than fixed pyrolysis equipment.
- Market may confuse charcoal residue with the Tigercat with biochar.

Template by TemplateLabs, TemplateLab.com/swot-analysis-template

1 (Tigercat International Inc., 2020). 2,3,5 (Tom Miles, personal communication, July 6, 2020) 4 (Hagemann, et al., 2018)

SWOT ANALYSIS

Activated Carbon (AC) & Ultraviolet Light (UV) – Legacy Solutions

STRENGTHS

- AC is the gold standard for filtration.[1]
- AC and UV are understood, legacy treatments for water filtration. Would-be clients know what they are.

WEAKNESSES

- AC is incredibly expensive (appx. $8,000 per ton)[2]
- Ultraviolet light is expensive (electricity) and labor-intensive.

OPPORTUNITIES

- When chemical variability is ironed out (feedstock, etc.), biochar is a possible replacement for AC.
- AC is incredibly expensive ($8,000 per ton) compared to biochar ($500 - $2,000 per ton).
- Ultraviolet light is expensive (electricity) and labor-intensive.

THREATS

- AC & UV are understood *legacy* water treatments of choice.
- The biochar information knowledge gap requires *continual* education to potential clients.

1 (Doug Griffes, P.E., personal communication, July 15, 2020)

APPENDIX D, Edited Financials, $1,500/Ton, 100% Sales

YR 1 Biochar Mfg Site Profit and Loss Forecast													
# of Kiln sets	-	-	-	-	-	-	-	10	10	10	10	10	10
# of Burns/day	-	-	-	-	-	-	-	20	20	20	20	20	20
Revenue		**Month 0**	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**	**Month 9**	**Month 10**	**Month 11**
Biochar		$0		$0	$0	$0	$0	$172,500	$250,125	$250,125	$250,125	$250,125	$250,125
Tipping Fee @ $8/yard				$0	$0	$0	$0	$52,800	$52,800	$52,800	$52,800	$52,800	$52,800
Shipping Revenue (10% of Rev)													
Net Revenue Total		**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$225,300**	**$302,925**	**$302,925**	**$302,925**	**$302,925**	**$302,925**
Cost of Services													
Biochar COGS		$0	$15,071	$41,485	$83,455	$139,760	$140,260	$225,215	$279,948	$279,753	$280,253	$282,750	$282,750
Shipping COGS													
COS Total		**$0**	**$15,071**	**$41,485**	**$83,455**	**$139,760**	**$140,260**	**$225,215**	**$279,948**	**$279,753**	**$280,253**	**$282,750**	**$282,750**
		N/A	N/A	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	100%	92%	92%	93%	93%	93%
GM		**$0**	**($15,071)**	**($41,485)**	**($83,455)**	**($139,760)**	**($140,260)**	**$85**	**$22,977**	**$23,172**	**$22,672**	**$20,175**	**$20,175**
GM %		N/A	N/A	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0%	8%	8%	7%	7%	7%
Ops Expenses													
Op Ex (see tab for detail)		$0	$27,351	$37,355	$34,655	$37,355	$37,355	$37,355	$37,679	$37,679	$37,679	$37,679	$37,679
Ops Expenses Total		**$0**	**$27,351**	**$37,355**	**$34,655**	**$37,355**	**$37,355**	**$37,355**	**$37,679**	**$37,679**	**$37,679**	**$37,679**	**$37,679**
Op Ex %		N/A	N/A	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	16.6%	12.4%	12.4%	12.4%	12.4%	12.4%
EBITDA		**$0**	**($42,422)**	**($78,839)**	**($118,109)**	**($177,114)**	**($177,614)**	**($37,269)**	**($14,702)**	**($14,507)**	**($15,007)**	**($17,504)**	**($17,504)**
EBITDA %		N/A	N/A	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	-17%	-5%	-5%	-5%	-6%	-6%
Depreciation		$0	$12,936	$25,276	$35,771	$35,849	$48,862	$48,954	$49,403	$54,245	$54,724	$55,203	$55,681
Net Income		**$0**	**($55,358)**	**($104,115)**	**($153,880)**	**($212,963)**	**($226,476)**	**($86,223)**	**($64,105)**	**($68,752)**	**($69,731)**	**($72,707)**	**($73,186)**
		N/A	N/A	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	-38%	-21%	-23%	-23%	-24%	-24%
YTD Net Income		$0	($55,358)	($159,473)	($313,353)	($526,317)	($752,793)	($839,016)	($903,121)	($971,873)	($1,041,604)	($1,114,311)	($1,187,497)

YR 2 Biochar Mfg Site Profit and Loss Forecast

Month 12	Yr 1	Year End Run Rate	Month 13	Month 14	Month 15	Month 16	Month 17	Month 18	Month 19	Month 20	Month 21	Month 22	Month 23	Month 24	Yr 2
10			20	20	20	20	20	20	20	20	20	20	20	20	
20			40	40	40	40	40	40	40	40	40	40	40	40	
$250,125	$1,673,250	$3,001,500	$500,250	$500,250	$500,250	$500,250	$500,250	$500,250	$500,250	$500,250	$500,250	$500,250	$500,250	$500,250	$6,003,000
$52,800	$369,600	$633,600	$105,600	$105,600	$105,600	$105,600	$105,600	$105,600	$105,600	$105,600	$105,600	$105,600	$105,600	$105,600	$1,267,200
	$0														$0
$302,925	**$2,042,850**	**$3,635,100**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$7,270,200**
$282,750	$2,333,450	$3,393,004	$306,418	$306,418	$306,418	$306,418	$306,418	$306,418	$306,418	$306,418	$306,418	$306,418	$306,418	$306,418	$3,677,018
	$0														$0
$282,750	**$2,333,450**	**$3,393,004**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$3,677,018**
93%		93%	51%	51%	51%	51%	51%	51%	51%	51%	51%	51%	51%	51%	
$20,175	**($290,600)**	**$242,096**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$3,593,182**
7%	-39%	7%	49%	49%	49%	49%	49%	49%	49%	49%	49%	49%	49%	49%	39%
$37,679	$437,497	$452,147	$37,519	$37,519	$37,519	$30,015	$30,015	$30,015	$27,514	$27,514	$27,514	$27,514	$27,514	$27,514	$367,684
$37,679	**$437,497**	**$452,147**	**$37,519**	**$37,519**	**$37,519**	**$30,015**	**$30,015**	**$30,015**	**$27,514**	**$27,514**	**$27,514**	**$27,514**	**$27,514**	**$27,514**	**$367,684**
12.4%	21.4%	12.4%	6.2%	6.2%	6.2%	5.0%	5.0%	5.0%	4.5%	4.5%	4.5%	4.5%	4.5%	4.5%	5.1%
($17,504)	**($728,097)**	**($210,051)**	**$261,913**	**$261,913**	**$261,913**	**$269,417**	**$269,417**	**$269,417**	**$271,918**	**$271,918**	**$271,918**	**$271,918**	**$271,918**	**$271,918**	**$3,225,498**
-6%	-36%	-6%	43%	43%	43%	44%	44%	44%	45%	45%	45%	45%	45%	45%	44%
$56,160	$533,064	$673,922	$56,282	$56,404	$56,525	$56,647	$56,769	$56,890	$57,012	$57,134	$57,255	$57,377	$57,499	$57,620	$683,413
($73,664)	**($1,261,161)**	**($883,973)**	**$205,631**	**$205,510**	**$205,388**	**$212,770**	**$212,648**	**$212,527**	**$214,906**	**$214,785**	**$214,663**	**$214,541**	**$214,419**	**$214,298**	**$2,542,086**
-24%	-62%	-24%	34%	34%	34%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%
($1,261,161)		($883,973)	$205,631	$411,141	$616,529	$829,299	$1,041,947	$1,254,474	$1,469,380	$1,684,164	$1,898,827	$2,113,369	$2,327,788	$2,542,086	

YR 3 Biochar Mfg Site Profit and Loss Forecast

Year End Run Rate	Month 25	Month 26	Month 27	Month 28	Month 29	Month 30	Month 31	Month 32	Month 33	Month 34	Month 35	Month 36	Yr 3	Year End Run Rate
	20 40	20 40	20 40	20 40	20 40	20 40	20 40	20 40	20 40	20 40	20 40	20 40		
$6,003,000	$500,250	$500,250	$500,250	$500,250	$500,250	$500,250	$500,250	$500,250	$500,250	$500,250	$500,250	$500,250	$6,003,000	$6,003,000
$1,267,200	$105,600	$105,600	$105,600	$105,600	$105,600	$105,600	$105,600	$105,600	$105,600	$105,600	$105,600	$105,600	$1,267,200	$1,267,200
													$0	
$7,270,200	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$605,850**	**$7,270,200**	**$7,270,200**
$3,677,018	$306,418	$306,418	$306,418	$306,418	$306,418	$306,418	$306,418	$306,418	$306,418	$306,418	$306,418	$306,418	$3,677,018	$3,677,018
													$0	
$3,677,018	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$306,418**	**$3,677,018**	**$3,677,018**
51%	51%	51%	51%	51%	51%	51%	51%	51%	51%	51%	51%	51%		51%
$3,593,182	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$299,432**	**$3,593,182**	**$3,593,182**
49%	49%	49%	49%	49%	49%	49%	49%	49%	49%	49%	49%	49%	39%	49%
$330,165	$27,514	$27,514	$27,514	$27,514	$27,514	$27,514	$27,514	$27,514	$27,514	$27,514	$27,514	$27,514	$330,165	$330,165
$330,165	**$27,514**	**$27,514**	**$27,514**	**$27,514**	**$27,514**	**$27,514**	**$27,514**	**$27,514**	**$27,514**	**$27,514**	**$27,514**	**$27,514**	**$330,165**	**$330,165**
4.5%	4.5%	4.5%	4.5%	4.5%	4.5%	4.5%	4.5%	4.5%	4.5%	4.5%	4.5%	4.5%	4.5%	4.5%
$3,263,017	**$271,918**	**$271,918**	**$271,918**	**$271,918**	**$271,918**	**$271,918**	**$271,918**	**$271,918**	**$271,918**	**$271,918**	**$271,918**	**$271,918**	**$3,263,017**	**$3,263,017**
45%	45%	45%	45%	45%	45%	45%	45%	45%	45%	45%	45%	45%	45%	45%
$691,443	$57,742	$57,864	$57,985	$58,107	$58,229	$58,350	$58,472	$58,594	$58,715	$58,837	$58,959	$59,080	$700,934	$708,965
$2,571,574	**$214,176**	**$214,054**	**$213,933**	**$213,811**	**$213,689**	**$213,568**	**$213,446**	**$213,324**	**$213,203**	**$213,081**	**$212,959**	**$212,838**	**$2,562,083**	**$2,554,052**
35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%
$2,571,574	$214,176	$428,231	$642,163	$855,974	$1,069,664	$1,283,232	$1,496,678	$1,710,002	$1,923,205	$2,136,286	$2,349,245	$2,562,083		$2,554,052

APPENDIX D, ii
Biochar Now's COGS for Operational Info

YR1 Biochar Mfg Site Manufacturing Cost Forecast															
	Month -1	Month 0	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Month 13
Key site data															
Kilns	0	0	0	10	10	10	20	20	20	20	20	20	20	20	20
crew days/week	0	0	0	5	7	7	7	7	7	7	7	7	7	7	7
Burns/day from income statement	0	0	0	15	30	30	60	60	60	60	60	60	60	60	60
Revenue/month	$0	$0	$0	$180,000	$522,000	$522,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000
Revenue	$0	$0	$0	$180,000	$522,000	$522,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000
EBITDA	$0	$0	($68,836)	$44,657	$318,519	$315,319	$723,297	$707,319	$707,190	$706,690	$704,193	$704,193	$704,193	$704,193	$666,072
EBITDA (% of Revenue)	#DIV/0!	#DIV/0!	#DIV/0!	24.8%	61.0%	60.4%	69.3%	67.8%	67.7%	67.7%	67.5%	67.5%	67.5%	67.5%	63.8%
Production Labor HC (both shifts)	0	0	6	10	10	10	10	14	14	14	14	14	14	14	14
Hours worked per HC per day	0	0	8	12	12	12	12	12	12	12	12	12	12	12	12
Work Days per month	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29
Burns planned for month	0	0	0	300	870	870	1,740	1,740	1,740	1,740	1,740	1,740	1,740	1,740	1,740
Manufacturing / COGS															
Direct Labor	$0	$0	$19,000	$31,667	$31,667	$31,667	$31,667	$44,333	$44,333	$44,333	$44,333	$44,333	$44,333	$44,333	$44,333
Equipment Technician	$0	$2,833	$3,500	$3,500	$3,500	$3,500	$3,500	$3,500	$3,333	$3,333	$3,333	$3,333	$3,333	$3,333	$3,333
Production Supervisor	$0	$3,467	$5,208	$5,208	$5,208	$5,208	$5,208	$5,208	$5,208	$5,208	$5,208	$5,208	$5,208	$5,208	$5,208
Payroll Tax / Benefits uplift (17%)	$0	$1,071	$4,710	$6,864	$6,864	$6,864	$6,864	$9,017	$8,989	$8,989	$8,989	$8,989	$8,989	$8,989	$8,989
MFG / COGS Salaries and Wages Exp	$0	$7,371	$32,419	$47,239	$47,239	$47,239	$47,239	$62,059	$61,864	$61,864	$61,864	$61,864	$61,864	$61,864	$61,863
Equipment Maint / Repair (1% of Rev)	$0	$1,000	$1,000	$1,000	$5,220	$5,220	$10,440	$10,440	$10,440	$10,440	$10,440	$10,440	$10,440	$10,440	$10,440
Equipment Lease Expense	$0	$6,700	$6,566	$6,566	$6,566	$6,566	$6,566	$7,724	$7,724	$7,724	$10,221	$10,221	$10,221	$10,221	$10,221
Utilities: REA power ($4.50/burn)	$0	$0	$0	$1,958	$3,915	$3,915	$7,830	$7,830	$7,830	$7,830	$7,830	$7,830	$7,830	$7,830	$7,830
Utilities: Propane Gas ($25.00/burn)	$0	$0	$0	$10,875	$21,750	$21,750	$43,500	$43,500	$43,500	$43,500	$43,500	$43,500	$43,500	$43,500	$43,500
Diesel Fuel ($3.91/burn)	$0	$0	$0	$1,701	$3,402	$3,402	$6,803	$6,803	$6,803	$6,803	$6,803	$6,803	$6,803	$6,803	$6,803
Bagging Supplies (4% of revenue)	$0	$0	$0	$7,200	$20,880	$20,880	$41,760	$41,760	$41,760	$41,760	$41,760	$41,760	$41,760	$41,760	$41,760
Log cost - $66.50 per kiln burn - 11 cubic yards of shred	$0	$0	$0	$19,950	$57,855	$57,855	$115,710	$115,710	$115,710	$115,710	$115,710	$115,710	$115,710	$115,710	$115,710
Contingency	$0	$0	$1,500	$1,500	$2,000	$2,500	$3,500	$3,500	$3,500	$4,000	$4,000	$4,000	$4,000	$4,000	$1,500
al COGS Expenses	$0	$15,071	$41,485	$97,988	$168,826	$169,326	$283,348	$299,326	$299,131	$299,631	$302,128	$302,128	$302,128	$302,128	$299,628

YR2 Biochar Mfg Site Manufacturing Cost Forecast

Month 14	Month 15	Month 16	Month 17	Month 18	Month 19	Month 20	Month 21	Month 22	Month 23	Month 24
20	20	20	20	20	20	20	20	20	20	20
7	7	7	7	7	7	7	7	7	7	7
60	60	60	60	60	60	60	60	60	60	60
$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000
$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000
$666,072	$665,572	$680,732	$679,732	$679,732	$684,952	$684,452	$684,452	$684,452	$684,452	$684,452
63.8%	63.8%	65.2%	65.1%	65.1%	65.6%	65.6%	65.6%	65.6%	65.6%	65.6%
14	14	14	14	14	14	14	14	14	14	14
12	12	12	12	12	12	12	12	12	12	12
29	29	29	29	29	29	29	29	29	29	29
1,740	1,740	1,740	1,740	1,740	1,740	1,740	1,740	1,740	1,740	1,740
$44,333	$44,333	$44,333	$44,333	$44,333	$44,333	$44,333	$44,333	$44,333	$44,333	$44,333
$3,333	$3,333	$3,333	$3,333	$3,333	$3,333	$3,333	$3,333	$3,333	$3,333	$3,333
$5,208	$5,208	$5,208	$5,208	$5,208	$5,208	$5,208	$5,208	$5,208	$5,208	$5,208
$8,989	$8,989	$8,989	$8,989	$8,989	$8,989	$8,989	$8,989	$8,989	$8,989	$8,989
$61,863	$61,863	$61,863	$61,863	$61,863	$61,863	$61,863	$61,863	$61,863	$61,863	$61,863
$10,440	$10,440	$10,440	$10,440	$10,440	$10,440	$10,440	$10,440	$10,440	$10,440	$10,440
$10,221	$10,221	$10,221	$10,221	$10,221	$10,221	$10,221	$10,221	$10,221	$10,221	$10,221
$7,830	$7,830	$7,830	$7,830	$7,830	$7,830	$7,830	$7,830	$7,830	$7,830	$7,830
$43,500	$43,500	$43,500	$43,500	$43,500	$43,500	$43,500	$43,500	$43,500	$43,500	$43,500
$6,803	$6,803	$6,803	$6,803	$6,803	$6,803	$6,803	$6,803	$6,803	$6,803	$6,803
$41,760	$41,760	$41,760	$41,760	$41,760	$41,760	$41,760	$41,760	$41,760	$41,760	$41,760
$115,710	$115,710	$115,710	$115,710	$115,710	$115,710	$115,710	$115,710	$115,710	$115,710	$115,710
$1,500	$2,000	$2,500	$3,500	$3,500	$3,500	$4,000	$4,000	$4,000	$4,000	$4,000
$299,628	$300,128	$300,628	$301,628	$301,628	$301,628	$302,128	$302,128	$302,128	$302,128	$302,128

YR3 Biochar Mfg Site Manufacturing C

Month 25	Month 26	Month 27	Month 28	Month 29	Month 30	Month 31
20	20	20	20	20	20	20
7	7	7	7	7	7	7
60	60	60	60	60	60	60
$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000
$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000
$680,162	$680,162	$680,162	$680,162	$680,162	$680,162	$680,162
65.1%	65.1%	65.1%	65.1%	65.1%	65.1%	65.1%
14	14	14	14	14	14	14
12	12	12	12	12	12	12
29	29	29	29	29	29	29
1,740	1,740	1,740	1,740	1,740	1,740	1,740
$44,333	$44,333	$44,333	$44,333	$44,333	$44,333	$44,333
$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000
$5,208	$5,208	$5,208	$5,208	$5,208	$5,208	$5,208
$9,612	$9,612	$9,612	$9,612	$9,612	$9,612	$9,612
$66,154	$66,154	$66,154	$66,154	$66,154	$66,154	$66,154
$10,440	$10,440	$10,440	$10,440	$10,440	$10,440	$10,440
$10,221	$10,221	$10,221	$10,221	$10,221	$10,221	$10,221
$7,830	$7,830	$7,830	$7,830	$7,830	$7,830	$7,830
$43,500	$43,500	$43,500	$43,500	$43,500	$43,500	$43,500
$6,803	$6,803	$6,803	$6,803	$6,803	$6,803	$6,803
$41,760	$41,760	$41,760	$41,760	$41,760	$41,760	$41,760
$115,710	$115,710	$115,710	$115,710	$115,710	$115,710	$115,710
$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000
$306,418	$306,418	$306,418	$306,418	$306,418	$306,418	$306,418

ost Forecast

Month 32	Month 33	Month 34	Month 35	Month 36
20	20	20	20	20
7	7	7	7	7
60	60	60	60	60
$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000
$1,044,000	$1,044,000	$1,044,000	$1,044,000	$1,044,000
$680,162	$680,162	$680,162	$680,162	$680,162
65.1%	65.1%	65.1%	65.1%	65.1%
14	14	14	14	14
12	12	12	12	12
29	29	29	29	29
1,740	1,740	1,740	1,740	1,740
$44,333	$44,333	$44,333	$44,333	$44,333
$7,000	$7,000	$7,000	$7,000	$7,000
$5,208	$5,208	$5,208	$5,208	$5,208
$9,612	$9,612	$9,612	$9,612	$9,612
$66,154	$66,154	$66,154	$66,154	$66,154
$10,440	$10,440	$10,440	$10,440	$10,440
$10,221	$10,221	$10,221	$10,221	$10,221
$7,830	$7,830	$7,830	$7,830	$7,830
$43,500	$43,500	$43,500	$43,500	$43,500
$6,803	$6,803	$6,803	$6,803	$6,803
$41,760	$41,760	$41,760	$41,760	$41,760
$115,710	$115,710	$115,710	$115,710	$115,710
$4,000	$4,000	$4,000	$4,000	$4,000
$306,418	$306,418	$306,418	$306,418	$306,418

APPENDIX E, i (Page 1)

Air Pollution Emission Notice Calculations for 20 Biochar Kilns

Equipment or Activity & Process/Consumption Limits

Facility Equipment ID	AIRS Point	Description	Annual Limit	
Kilns (TONS clean wood input annually)	001	The total number of kiln pairs that operate on a given day will adjust up or down to maintain the annual emissions limits. Each operating kiln is equipped with an afterburner stack for emission control. Clean wood is processed under low-oxygen conditions to convert the wood to biochar, a charcoal-like material. Off gases geneated during the process pass through an afterburner for emission control before being emitted to the atmosphere. ***(Tons clean wood processing per year to produce biochar.)***	**8,050**	
Kilns (hourly)	*001*	Number of kiln cycle hours per year for TOTAL number of kilns	**70,000**	
Kilns	001	Natural gas/propane consumption ***(MMBTUs)****	**1,111,437**	
Log sawing & splitting	002	Clean wood is prepared to be charged into the kilns.		
Sizing & Packaging	003	Biochar product is crushed and screened to generate products of various particle sizes, which are then loaded for shipping.		

Emissions Factors

Point 001: Kilns

Pollutant	Emission Factor (*uncontrolled*), Lbs/Ton of Raw Wood (u.n.o.)	Source	TOTAL ANNUAL Lbs Emissions/ TOTAL Raw Wood Tons (u.n.o.) *UNCONTROLLED*	TOTAL ANNUAL Lbs Emissions/ TOTAL Raw Wood Tons (u.n.o.) *WITH CONTROLS AS NOTED*
PM	0.19		1,529.5	1,529.5
PM10	0.18		1,449.0	1,449.0
PM2.5	0.18		1,449.0	1,449.0
NOx	0.14	*Lbs/hour*	9,800.0	9,800.0
CO	0.12	*Lbs/hour*	8,400.0	8,400.0
VOC	9.30		74,865.0	3,743.3
Methanol	4.00		32,200.0	1,610.0

* 95% control for VOCs and methanol

Point 002a: Log Shredding

Pollutant	Emission Factor, Lbs/Ton of Raw Wood (*uncontrolled*)	Source & Control	TOTAL ANNUAL Lbs Emissions/ TOTAL Raw Wood Tons (u.n.o.) *UNCONTROLLED*	TOTAL ANNUAL Lbs Emissions/ TOTAL Raw Wood Tons (u.n.o.) *WITH CONTROLS AS NOTED*
PM	0.035	EPA Region 10 Memorandum[1]. Equipment is covered with a shroud allowing for 50% control efficiency for partial enclosure.	281.8	140.9
PM10	0.0175		140.9	70.4
PM2.5	0.00875		70.4	35.2

[1] "Particulate Matter Potential to Emit Emission Factors for Activities at Sawmills ...." May 8, 2014.

Point 002b: Kiln Loading

Pollutant	Emission Factor/Ton of Raw Wood	Source	TOTAL ANNUAL Lbs Emissions/ TOTAL Raw Wood Tons (u.n.o.) *UNCONTROLLED*	TOTAL ANNUAL Lbs Emissions/ TOTAL Raw Wood Tons (u.n.o.) *WITH CONTROLS AS NOTED*
PM	0.0015	EPA Region 10 Memorandum[1]	12.1	12.1
PM10	0.0007		5.6	5.6
PM2.5	0.0001		0.8	0.8

[1] "Particulate Matter Potential to Emit Emission Factors for Activities at Sawmills ...." May 8, 2014.

Point 003: Sizing & Packaging

Pollutant	Emission Factor/Ton of Product	Source & Control	TOTAL ANNUAL Lbs Emissions/ TOTAL Tons Product (u.n.o.) *UNCONTROLLED*	TOTAL ANNUAL Lbs Emissions/ TOTAL Tons Product (u.n.o.) *WITH CONTROLS AS NOTED*
PM	0.0562	Best engineering judgment. Operation is housed inside a building allowing for control efficiency of 85%.	113.1	17.0
PM10	0.0208		41.9	6.3
PM2.5	0.0208		41.9	6.3

* Note: "CP" stands for *criteria pollutants*, and "NCP" stands for *non-criteria pollutants* as defined by the Colorado Department of Public Health and Environment in Regulation 3, Appendix B. NCP are also known as *hazardous air pollutants (HAP)*. Calculations initially sourced from COLORADO Air Pollution Control Division, Permit number: 15WE1395, April 25, 2018, for Biochar Now. Adaptations made to 5280 Recycling Solutions' specific needs.

*Note: One cubic foot of propane has 2,516 BTUs. One cubic foot of NG has 1,030 BTUs. Therefore, propane has ***2.442718447*** as much energy per unit of volume than NG. Stationary Source Permitting and Air Pollutant Emission Notice Requirements. Retrieved July 29, 2020, from COLORADO Department of Public Health & Environment: https://drive.google.com/file/d/1_0oq-e_bYz_DT1y9h_rwn-O3gPQmQqa-/view, pp. 4, 5, 48, 50.

APPENDIX E, i (Page 2, cont.)

Air Pollution Emission Notice Calculations for 20 Biochar Kilns

Facility Equipment ID	AIRS Point	Tons Per Year Emission Type - ***UNCONTROLLED***								Emission Type
		PM	PM_{10}	$PM_{2.5}$	NOx	SO_2	VOC	CO	Methanol	
Kilns	001	1,529.5	1,449.0	1,449.0	9,800.0		74,865.0	8,400.0	32,200.0	Point
Log Shredding & Kiln Loading	002	293.8	146.5	71.2						Point
Product Sizing & Packaging	003	113.1	41.9	41.9						Point
TOTAL Point (Lbs)		**1,936.4**	**1,637.4**	**1,562.1**	**9,800.0**	**-**	**74,865.0**	**8,400.0**	**32,200.0**	
TOTAL Point (Tons)		**0.97**	**0.82**	**0.78**	**4.90**	**-**	**37.43**	**4.20**	**16.10**	
Pollutant Category*		**CP**	**CP**	**CP**	**CP**	**CP**	**CP**	**CP**	**NCP**	

Facility Equipment ID	AIRS Point	Tons Per Year Emission Type - ***CONTROLLED***								Emission Type
		PM	PM_{10}	$PM_{2.5}$	NOx	SO_2	VOC	CO	Methanol	
Kilns	001	1,529.5	1,449.0	1,449.0	9,800.0		3,743.3	8,400.0	1,610.0	Point
Log Shredding & Kiln Loading	002	153.0	76.1	36.0						Point
Product Sizing & Packaging	003	17.0	6.3	6.3						Point
TOTAL Point (Lbs)		**1,699.4**	**1,531.4**	**1,491.3**	**9,800.0**	**-**	**3,743.3**	**8,400.0**	**1,610.0**	
TOTAL Point (Tons)		**0.85**	**0.77**	**0.75**	**4.90**	**-**	**1.87**	**4.20**	**0.81**	
Pollutant Category*		**CP**	**CP**	**CP**	**CP**	**CP**	**CP**	**CP**	**NCP**	

UNCONTROLLED	**Pounds**	**Tons**
TOTAL CP (Criteria Pollutants)	**98,200.9**	**49.1**
TOTAL NCP (Non-Criteria Pollutants)	**32,200.0**	**16.1**

CONTROLLED	**Pounds**	**Tons**
TOTAL CP (Criteria Pollutants)	**26,665.3**	**13.3**
TOTAL NCP (Non-Criteria Pollutants)	**1,610.0**	**0.8**

TYPE OF FEE	**UNIT**	**2020 CAPS (CDPHE)**	**TOTAL**
Permit processing	**Per hour**	$ 108.12	$ 864.96
Air Pollutant Emissions Notices (APEN filing fee)	**x1**	$ 216.00	$ 216.00
Emissions, *regulated* (criteria) pollutants	**Per ton**	$ 32.00	$ 426.65
Hazardous pollutants (non-criteria, HAPs)	**Per ton**	$ 216.00	$ 173.88
TOTAL APEN PERMIT FEE FOR NUMBER OF KILNS			**$ 1,681.49**
Number of Kilns	***20***		

* Note: "CP" stands for *criteria pollutants*, and "NCP" stands for *non-criteria pollutants* as defined by the Colorado Department of Public Health and Environment in Regulation 3, Appendix B. NCP are also known as *hazardous air pollutants (HAP)*. Calculations initially sourced from COLORADO Air Pollution Control Division, Permit number: 15WE1395, April 25, 2018, for Biochar Now. Adaptations made to 5280 Recycling Solutions' specific needs.

Source: COLORADO Department of Public Health & Environment. (2020, Feb. 14). DEPARTMENT OF PUBLIC HEALTH AND ENVIRONMENT Air Quality Control Commission REGULATION NUMBER 3 Stationary Source Permitting and Air Pollutant Emission Notice Requirements. Retrieved July 29, 2020, from COLORADO Department of Public Health & Environment: https://drive.google.com/file/d/1_0oq-e_bYz_DT1y9h_rwn-O3gPQmQqa-/view, pp. 4, 5, 48, 50.

COLORADO
Air Pollution Control Division
Department of Public Health & Environment

CONSTRUCTION PERMIT

Permit number: **15WE1395** **Issuance: 4**

Date issued: April 25, 2018

Issued to: **Biochar Now, LLC**

Facility Name: Berthoud Plant
Plant AIRS ID: 123-9E2C
Physical Location: 19500 Weld County Road 7
County: Weld County
General Description: Biochar production facility

Equipment or activity subject to this permit:

Facility Equipment ID	AIRS Point	Description
KILNS	001	The total number of kiln pairs that operate on a given day will adjust up or down to maintain the annual emissions limits per condition 2 below. Each operating kiln is equipped with an afterburner stack for emission control. Clean wood is processed under low oxygen conditions to convert the wood to biochar, a charcoal- like material. Off gasses generated during the process pass through an afterburner for emission control before being emitted to the atmosphere.
Log sawing and splitting	002	Clean wood is prepared to be charged into the kilns.
Sizing and Packaging	003	Biochar product is crushed and screened to generate products of various particle sizes which are then loaded for shipping.
Fugitive	006	Fugitive dust emissions from haul road traffic

Facility Equipment ID	AIRS Point	Description
Generator	007	One (1) John Deere Diesel Generator, Model 4045TF285; Serial number: 20107179 Design rating: 99 HP Site Rating: 78 HP Displacement 1.13 liter/cylinder Date of Manufacturer: 2011 Colorado Entry Date: 2015 Subject to NSPS Subpart IIII Tier 3 requirements
Generator	008	One (1) Isuzu diesel engine, Model 4HK1X; Serial number: 5SLBG1628CL010999, Design rating: 173 HP, Site Rating: 134HP Displacement 1.3 liter/cylinder Date of Manufacture: 2011 Colorado Entry Date: 2012 Subject to NSPS Subpart IIII Tier 3 requirements
Note 1: The clean wood used in the Biochar process is limited to clean lumber and wood waste only from forestry, agricultural and urban wood sources. Clean lumber and wood waste do not include wood products that have been painted, pigment-stained, or pressure treated by compounds such as chromate copper arsenate, pentachlorophenol or creosote or manufactured wood products that contain adhesives or resins (e.g. plywood, particle board, flake board and oriented strand board) or incidental debris. Painted wood in the form of trees marked with tree marking paint or lumber with similar identifying marks is allowed. Any change or addition to the type of wood used in the Biochar process will require a modification to this permit, prior to beginning use of the new wood type		
Note 2: The engine(s) may be replaced with another engine in accordance with the temporary engine replacement provision or with the same manufacturer and model engine as submitted to the Division per Requirements to Self-Certify for Final Authorization in accordance with the permanent replacement provision of the Alternate Operating Scenario (AOS), included in this permit as Attachment A.		

THIS PERMIT IS GRANTED SUBJECT TO ALL RULES AND REGULATIONS OF THE COLORADO AIR QUALITY CONTROL COMMISSION AND THE COLORADO AIR POLLUTION PREVENTION AND CONTROL ACT C.R.S. (25-7-101 et seq), TO THOSE GENERAL TERMS AND CONDITIONS INCLUDED IN THIS DOCUMENT AND THE FOLLOWING SPECIFIC TERMS AND CONDITIONS:

REQUIREMENTS TO SELF-CERTIFY FOR FINAL APPROVAL

1. This construction permit represents final permit approval to operate this emissions source. Therefore, it is not necessary to self-certify. (Regulation Number 3, Part B, III.G.5).

EMISSION LIMITATIONS AND RECORDS

2. Emissions of air pollutants must not exceed the following limitations. Monthly records of the actual emission rates must be maintained by the applicant and made available to the Division for inspection upon request. (Reference: Regulation Number 3, Part B, II.A.4.)

Annual Limits:

Facility Equipment ID	AIRS Point	Tons per year Emission Type								Emission Type
		PM	PM_{10}	$PM_{2.5}$	NO_x	SO_2	VOC	CO	methanol	
Kilns	001	1.7	1.6	1.6	13.5	0	4.2	11.6	1.8	Point
Log Shred/Load	002	0.5	0.2	0.1	---	---	---	---	---	Point
Product Sizing/ packaging	003	0.1	0.1	0.1	---	---	---	---	---	Point
Fugitve Dust	006	2.0	0.6	0.1	---	---	---	---	---	Fugitive
Generator	007	0.2	0.2	0.2	2.0	0.6	1.1	2.1	---	Point
Generator	008	0.2	0.2	0.2	1.6	0.8	0.6	0.7	---	Point
Total point		2.7	2.3	2.2	17.1	1.4	5.9	14.4	1.8	
Total fugitive		2.0	0.6	0.1	---	---	---	---	---	
Total point + fugitive		4.7	2.9	2.3	17.1	1.4	5.9	14.4	1.8	

Facility-wide emissions of each individual hazardous air pollutant must not exceed 8.0 tpy.

Facility-wide emissions of total hazardous air pollutants must not exceed 20.0 tpy.

The facility-wide emissions limitation for hazardous air pollutants applies to all permitted emission units at this facility.

Compliance with the annual limits, for both criteria and hazardous air pollutants, must be determined on a rolling twelve (12) month total. By the end of each month a new twelve month total is calculated based on the previous twelve months' data. The permit holder must calculate actual emissions each month and keep a compliance record on site or at a local field office with site responsibility for Division review.

The owner or operator must use the emission factors found in "Notes to Permit Holder" to calculate emissions and show compliance with the limits. The owner or operator must submit an Air Pollutant Emission Notice (APEN) and receive a modified permit prior to the use of any other method of calculating emissions.

3. Compliance with the fugitive emission limits must be demonstrated by not exceeding the process limitation limits listed below in condition 6 and by following the particulate emissions control plan in Attachment B (Reference: Regulation Number 3, Part B, III.E.)

4. The following control equipment must be maintained and operated to ensure satisfactory performance. The owner or operator must monitor compliance with this condition through the results of approved compliance tests (when required), compliance with the Operating and Maintenance Plan, compliance records, and other methods as approved by the Division. (Reference: Regulation Number 3, Part B, III.E.)

Facility Equipment ID	AIRS Point	Control Device	Controlled Pollutants
Kilns	001	Afterburners - for operating kilns	Particulate NOx CO VOC Methanol
Shred/Load	002	Shroud – partial enclosure	Particulate
Size/Package	003	Building	Particulate

5. Total facility emissions of criteria pollutants must not exceed the limitations stated in condition 2. This facility's activities/throughput must be limited by the emission limits specified in this permit. The number of kilns operated on a daily basis may be adjusted based on the emission factors as derived from the stack testing to insure that the emission limits of condition 2 are not exceeded. Monthly records of the actual activities, emissions of criteria and non-criteria reportable pollutants must be maintained by the applicant and made available to the Division for inspection upon request. (Reference Regulation Number 3, Part E.)

PROCESS LIMITATIONS AND RECORDS

6. This source must be limited to the following maximum consumption, processing and/or operational rates as listed below. Monthly records of the actual process rate must be maintained by the applicant and made available to the Division for inspection upon request. (Reference: Regulation Number 3, Part B, II.A.4)

Process/Consumption Limits

Facility Equipment ID	AIRS Point	Process Parameter	Annual Limit
Kilns	**001**	Clean wood processing to produce biochar (tons)	17,666
Kilns	**001**	Natural gas/propane consumption (MM btu)	24,090
Generator	**007**	Hours of operation	6,388
Generator	**008**	Hours of operation	5,475

For each generator, compliance with the consumption limits will be demonstrated by installing a non-resettable hour meter on each engine and recording the hours of the engine's operation.

Compliance with the yearly process limits must be determined on a rolling twelve (12) month total. By the end of each month a new twelve-month total is calculated based on the previous twelve months' data. The permit holder must calculate monthly process rates and keep a compliance record on site or at a local field office with site responsibility, for Division review.

STATE AND FEDERAL REGULATORY REQUIREMENTS

7. Visible emissions must not exceed twenty percent (20%) opacity during normal operation of the source. During periods of startup, process modification, or adjustment of control equipment visible emissions must not exceed 30% opacity for more than six minutes in any sixty

consecutive minutes. Opacity must be determined using EPA Method 9. (Reference: Regulation Number 1, II.A.1. & 4.)

8. The diesel engine (AIRS ID 007) is subject to the New Source Performance Standards requirements of Regulation Number 6, Part A , Subpart IIII, Standards of Performance for Stationary Compression Ignition Internal Combustion Engines (CI ICE) including, but not limited to, the following:

[The requirements below reflect the rule language of 40 CFR Part 60 Subpart IIII published in the Federal Register on 1/30/2013. However, if revisions to this Subpart are published at a later date, the owner or operator is subject to the requirements contained in the revised version of 40 CFR Part 60, Subpart IIII.]

a. Emissions of Non-Methane Hydrocarbons and Nitrogen Oxides combined shall not exceed 4.7 grams per kilowatt hour.

b. Emissions of Carbon Monoxide shall not exceed 5.0 grams per kilowatt hour.

c. Emissions of Particulate Matter shall not exceed 0.40 grams per kilowatt hour.

d. All fuel used shall meet the following specifications:

(1) Sulfur content shall not exceed 15 ppm.

(2) Have a minimum cetane index of 40 **or**

Have a maximum aromatic compound content of 35% by volume.

Compliance shall be demonstrated by maintaining copies of the fuel specifications provided by the supplier on-site or in a readily accessible location and made available to the Division for inspection upon request.

e. All engines and control devices must be installed, configured, operated, and maintained according to the specifications and instructions provided by the engine manufacturer.

f. If engine is equipped with a diesel particulate filter, the filter must be installed with a backpressure monitor that notifies the owner or operator when the high backpressure limit of the engine is approached. Records shall be kept of any corrective action taken after the backpressure monitor has notified the owner or operator that the high backpressure limit is approached.

9. The diesel engine (AIRS ID 008) is subject to the New Source Performance Standards requirements of Regulation Number 6, Part A , Subpart IIII, Standards of Performance for Stationary Compression Ignition Internal Combustion Engines (CI ICE) including, but not limited to, the following:

[The requirements below reflect the rule language of 40 CFR Part 60 Subpart IIII published in the Federal Register on 1/30/2013. However, if revisions to this Subpart are published at a later date, the owner or operator is subject to the requirements contained in the revised version of 40 CFR Part 60, Subpart IIII.]

a. Emissions of Non-Methane Hydrocarbons and Nitrogen Oxides combined shall not exceed 4.0 grams per kilowatt hour

b. Emissions of Carbon Monoxide shall not exceed 5.00 grams per kilowatt hour.

c. Emissions of Particulate Matter shall not exceed 0.30 grams per kilowatt hour.

d. All fuel used shall meet the following specifications:

(1) Sulfur content shall not exceed 15 ppm.

(2) Have a minimum cetane index of 40 **or**

Have a maximum aromatic compound content of 35% by volume.

Compliance shall be demonstrated by maintaining copies of the fuel specifications provided by the supplier on-site or in a readily accessible location and made available to the Division for inspection upon request.

e. All engines and control devices must be installed, configured, operated, and maintained according to the specifications and instructions provided by the engine manufacturer.

f. If engine is equipped with a diesel particulate filter, the filter must be installed with a backpressure monitor that notifies the owner or operator when the high backpressure limit of the engine is approached. Records shall be kept of any corrective action taken after the backpressure monitor has notified the owner or operator that the high backpressure limit is approached.

10. In addition, the following requirements of Regulation Number 6, Part A, Subpart A, General Provisions, apply

a. At all times, including periods of start-up, shutdown, and malfunction, the facility and control equipment shall, to the extent practicable, be maintained and operated in a manner consistent with good air pollution control practices for minimizing emissions. Determination of whether or not acceptable operating and maintenance procedures are being used will be based on information available to the Division, which may include, but is not limited to, monitoring results, opacity observations, review of operating and maintenance procedures, and inspection of the source. (Reference: Regulation Number 6, Part A. General Provisions from 40 CFR 60.11

b. No article, machine, equipment or process shall be used to conceal an emission which would otherwise constitute a violation of an applicable standard. Such concealment includes, but is not limited to, the use of gaseous diluents to achieve compliance with an opacity standard or with a standard which is based on the concentration of a pollutant in the gases discharged to the atmosphere. (§ 60.12)

11. This source is subject to the odor requirements of Regulation Number 2. (State only enforceable)

12. This source is located in an ozone non-attainment or attainment-maintenance area and subject to the Reasonably Available Control Technology (RACT) requirements of Regulation Number 3, Part B, III.D.2. The requirements of condition numbers 4, 8, and 9 above were determined to be RACT for this source.

OPERATING & MAINTENANCE REQUIREMENTS

13. The owner or operator must follow the most current operating and maintenance (O&M) plan and recordkeeping format approved by the Division in order to demonstrate compliance on an ongoing basis with the requirements of this permit. Revisions to the O&M plan are subject to Division approval prior to implementation. Note that the Division may modify the monitoring requirements as part of the Title V Operating Permit if this facility is subject to Title V permitting (Reference: Regulation Number 3, Part B, III.G.7.).

    The owner or operator shall include in the Operation and Maintenance Plan the agreements with clean wood suppliers and / or the procedures for minimizing, to the extent practical, the amount of contaminants in the clean wood that may have entered the clean wood (unintentionally) prior to delivery to the facility or contaminants that may have entered the clean wood stored on site.

COMPLIANCE TESTING AND SAMPLING

Periodic Testing Requirements

14. The owner or operator must demonstrate continued compliance with the annual Kiln emission limits listed in condition 2 by completing a source compliance test every two years. The test must be conducted no earlier than 21 months after the last compliance test and must be completed prior to 27 months after the last compliance test. (The last compliance test was conducted in September 2017)

    This test must be conducted on a total of 3 kiln/afterburner units to measure the emission rate(s) over the entire process duration for the pollutants listed below in order to demonstrate compliance with the annual emission limits listed in Condition 2. The average of the emissions rates for the 3 tests must be used to show compliance with the emission requirements.

    The test protocol must be in accordance with the requirements of the Air Pollution Control Division Compliance Test Manual and must be submitted to the Division for review and approval at least thirty (30) days prior to testing. No compliance test shall be conducted without prior approval from the Division. Any compliance test conducted to show compliance with a monthly or annual emission limitation must have the results projected up to the monthly or annual averaging time by multiplying the test results by the allowable number of operating hours for that averaging time (Reference: Regulation Number 3, Part B., III.G.3)

    -Particulate Matter
    PM10 and PM2.5 (filterable and condensable) using EPA approved methods.

15. Replacements of any of the diesel engines (AIRS ID 007 and 008) listed in this permit, completed as Alternative Operating Scenarios may be subject to additional testing requirements as specified in Attachment A.

ADDITIONAL REQUIREMENTS

16. The terms, conditions and information contained in Attachments A and B are hereby incorporated into this permit, and are enforceable as if fully set forth herein including, but not limited to, emission point description, emission factor summary, emission limits or other limitations, controls, and specific requirements. (Reference: Regulation Number 3, Part B III.E.)

17. All previous versions of this permit are canceled upon issuance of this permit.

18. The permit number must be marked on the subject equipment for ease of identification. (Reference: Regulation Number 3, Part B, III.E.) (State only enforceable).

19. A Revised Air Pollutant Emission Notice (APEN) must be filed: (Reference: Regulation Number 3, Part A, II.C.)

    a. By April 30 of the year following a significant increase in emissions. A significant increase in emissions is defined as follows:

       For any criteria pollutant:

       For sources emitting **less than 100 tons per year**, a change in actual emissions of five tons per year or more, above the level reported on the last APEN submitted; or

       For volatile organic compounds (VOC) and nitrogen oxide (NOx) sources in an ozone non-attainment area emitting **less than 100 tons of VOC or nitrogen oxide per year**, a change in actual emissions of one ton per year or more or five percent, whichever is greater, above the level reported on the last APEN submitted; or

       For sources emitting **100 tons per year or more of a criteria pollutant**, a change in actual emissions of five percent or 50 tons per year or more, whichever is less, above the level reported on the last APEN submitted; or

       For sources emitting **any amount of lead**, a change in actual emissions, above the level reported on the last APEN submitted, of fifty (50) pounds of lead

       For any non-criteria reportable pollutant:

       If the emissions increase by 50% or five (5) tons per year, whichever is less, above the level reported on the last APEN submitted to the Division.

    b. Whenever there is a change in the owner or operator of any facility, process, or activity; or

    c. Whenever new control equipment is installed, or whenever a different type of control equipment replaces an existing type of control equipment; or

    d. Whenever a permit limitation must be modified; or

    e. No later than 30 days before the existing APEN expires.

20. The requirements of Colorado Regulation Number 3, Part D apply at such time that any stationary source or modification becomes a major stationary source or major modification solely by virtue of a relaxation in any enforceable limitation that was established after August 7, 1980, on the capacity of the source or modification to otherwise emit a pollutant such as a restriction on hours of operation (Colorado Regulation Number 3, Part D, V.A.7.B).

    With respect to this Condition, Part D requirements may apply to future modifications if emission limits are modified to equal or exceed the following threshold levels:

Facility Equipment ID	AIRS Point	Equipment Description	Pollutant	Emissions - tons per year	
				Threshold	current permit limit
plant	001-003 and 007, 008	Biochar production	PM10	250	2.3
			PM2.5	250	2.2
			CO	250	14.4
			NOx	100	17.1
			VOC	100	5.9

GENERAL TERMS AND CONDITIONS:

21. This permit and any attachments must be retained and made available for inspection upon request. The permit may be reissued to a new owner by the Division as provided in Regulation Number 3, Part B, II.B upon a request for transfer of ownership and the submittal of a revised APEN and the required fee.

22. If this permit specifically states that final approval has been granted, then the remainder of this condition is not applicable. Otherwise, the issuance of this construction permit is considered initial approval and does not provide "final" approval for this activity or operation of this source. Final approval of the permit must be secured from the APCD in writing in accordance with the provisions of 25-7-114.5(12)(a) C.R.S. and AQCC Regulation Number 3, Part B, III.G. Final approval cannot be granted until the operation or activity commences and has been verified by the APCD as conforming in all respects with the conditions of the permit. Once self-certification of all points has been reviewed and approved by the Division, it will provide written documentation of such final approval. **Details for obtaining final approval to operate are located in the Requirements to Self-Certify for Final Approval section of this permit.** The operator must retain the permit final approval letter issued by the Division after completion of self-certification with the most current construction permit.

23. This permit is issued in reliance upon the accuracy and completeness of information supplied by the applicant and is conditioned upon conduct of the activity, or construction, installation and operation of the source, in accordance with this information and with representations made by the applicant or applicant's agents. It is valid only for the equipment and operations or activity(ies) specifically identified in this permit. If subsequent operations or testing at the source indicate the information supplied to obtain this permit and relied upon in the creation and issuance of this permit is inaccurate, the source must submit an application to modify the permit to address the inaccuracy(ies). (Reference: Regulation Number 3, Part B III.E.)

By: ______________________
Michael Harris, P. E.
Permit Engineer

By: ______________________
R K Hancock III, P.E.
Construction Permits Unit Supervisor

Permit History

Issuance	Date	Description
Issuance 4	This Issuance	Permit issued as Final Approval. Permit modified to show as-built equipment. Emission factors and emission limits were adjusted based on the results of stack testing.
Issuance 3	March 13, 2017	Change allowable wood for processing from "raw" wood to "clean" wood and define what clean wood is. No change to emission limits or other limits in the permit.
Issuance 2	July 11, 2016	Reissue permit with change in address. No other changes.
Issuance 1	March 8, 2016	Issued to Biochar Now, LLC. Upon issuance of this permit, permit 12PO2335 is canceled.

Notes to Permit Holder (as of date of permit issuance):

1) The production or raw material processing limits and emission limits contained in this permit are based on the production/processing rates requested in the permit application. These limits may be revised upon request of the permittee providing there is no exceedence of any specific emission control regulation or any ambient air quality standard. A revised air pollutant emission notice (APEN) and application form must be submitted with a request for a permit revision. (Reference: Regulation Number 3, Part B II.A.4.)

2) This source is subject to the Common Provisions Regulation Part II, Subpart E, Affirmative Defense Provision for Excess Emissions During Malfunctions. The permittee must notify the Division of any malfunction condition which causes a violation of any emission limit or limits stated in this permit as soon as possible, but no later than noon of the next working day, followed by written notice to the Division addressing all of the criteria set forth in Part II.E.1. of the Common Provisions Regulation. See: https://www.colorado.gov/pacific/cdphe/aqcc-regs.

3) The following emissions of non-criteria reportable air pollutants are estimated based upon the process limits as indicated in this permit. This information is listed to inform the operator of the Division's analysis of the specific compounds emitted if the source(s) operate at the permitted limitations.

AIRS Point	Pollutant	CAS #	Uncontrolled Emission Rate (lb/yr) (1)	Are the emissions reportable? (2)	Controlled Emission Rate (lb/yr)
001	Methanol	71432	70,700	YES	3,550

(1) Uncontrolled emissions based on stack test results
(2) A non criteria reportable pollutant is reportable if emissions exceed 250 pounds per year.

4) The emission levels contained in this permit are based on the following emission factors:

Point 001: Kilns

Pollutant	Emission Factor - uncontrolled	Source
PM	0.19 lb/ton of raw wood	2017 stack testing
PM10	0.18 lb/ton of raw wood	2017 stack testing
PM2.5	0.18 lb/ton of raw wood	2017 stack testing

Pollutant	Emission Factor - uncontrolled	Source
NO_x	0.14 lb/hour	2015 emissions testing
CO	0.12 lb/hour	Manufacturer
VOC	9.3 lb/ton of raw wood	2017 stack testing
Methanol	4 lb/ton of raw wood	2017 stack testing

1) 95% control for VOCs and Methanol

Point 002: Log shredding

Pollutant	Uncontrolled		Control
	lb/ton of clean wood	Source	
PM	0.035	EPA region 10 memorandum (1)	Equipment is covered with a shroud allowing for 50% control efficiency for partial enclosure
PM10	0.0175		
PM2.5	0.00875		

(1) "Particulate Matter Potential to Emit Emission Factors for Activities at Sawmills…." May 8, 2014

Kiln loading

Pollutant	lb/ton of raw wood	Source
PM	0.0015 lb/ton	EPA region 10 memorandum
PM10	0.0007 lb/ton	
PM2.5	0.0001 lb/ton	

Point 003: Sizing and packaging

Pollutant	lb/ton of product	Source	Control
PM	0.0562	Best Engineering Judgement	Operation is housed inside a building allowing for control efficiency of 85%
PM10	0.0208		
PM2.5	0.0208		

Point 007 Generator 58 kW (78 hp site rated) John Deere (Tier III compliant)
Annual operating hours 6,388

Pollutant	Emission Factor	Units	Source
NOx	7.73e-3	lb/hp-hr	NSPS Tier 3
CO	8.23e-3	lb/hp-hr	NSPS Tier 3
PM	3.29e-4	lb/hp-hr	NSPS Tier 3
SO2	2.05E-03	lb/hp-hr	AP42 Table 3.3-1
NMHC (VOC)	4.40e-3	lb/hp-hr	NSPS Tier 3

Point 008 Generator 100 kW (134 hp site rated) Isuzu (Tier III compliant)
Annual hours of operation 5,475

Pollutant	Emission Factor	Units	Source
NOx	4.28e-3	lb/hp-hr	manufacturer
CO	1.81e-3	lb/hp-hr	manufacturer
PM	2.87e-4	lb/hp-hr	manufacturer
SO2	2.05E-03	lb/hp-hr	AP42 Table 3.3-1
NMHC (VOC)	1.46e-3	lb/hp-hr	manufacturer

5) In accordance with C.R.S. 25-7-114.1, each Air Pollutant Emission Notice (APEN) associated with this permit is valid for a term of five years from the date it was received by the Division. A revised APEN must be submitted no later than 30 days before the five-year term expires. Please refer to the most recent annual fee invoice to determine the APEN expiration date for each emissions point associated with this permit. For any questions regarding a specific expiration date call the Division at (303)-692-3150.

6) This facility is classified as follows:

Applicable Requirement	Status
Operating Permit	Synthetic Minor Source VOC, HAP
NANSR	Synthetic Minor Source VOC

7) The diesel engines(AAIRS 007 and 008) are subject to 40 CFR, Part 63, Subpart ZZZZ - **National Emission Standards for Hazardous Air Pollutants for Reciprocating Internal Combustion Engines** (**Federally enforceable only**). A copy of the complete subpart is available on the EPA website at: http://www.epa.gov/ttn/atw/rice/ricepg.html. All initial notifications, compliance demonstrations, and required documentation should be submitted directly to U.S. EPA Region 8 and copies sent to the Colorado Air Pollution Control Division

8) Full text of the Title 40, Protection of Environment Electronic Code of Federal Regulations can be found at the website listed below:

http://www.ecfr.gov/cgi-bin/text-idx?gp=&SID=2a3fbebe8f5c2f47006ad49ae4b4c080&mc=true&tpl=/ecfrbrowse/Title40/40tab_02.tpl

Part 60: Standards of Performance for New Stationary Sources		
NSPS	60.4200-60.4219	Subpart IIII
Part 63: National Emission Standards for Hazardous Air Pollutants for Source Categories		
MACT	63.6580-63.6675	Subpart ZZZZ

9) Manufacturer's certification of compliance with the New Source Performance Standards Subpart IIII was submitted with the original application for this permit.

10) The permit holder is required to pay fees for the processing time for this permit. An invoice for these fees will be issued after the permit is issued. Failure to pay the invoice will result in revocation of this permit. The permit holder must pay the invoice within 30 days of receipt of the invoice (Reference: Regulation Number 3, Part A, VI.B).

11) Unless specifically stated otherwise, the general and specific conditions contained in this permit have been determined by the Division to be necessary to assure compliance with the provisions of Section 25-7-114.5(7)(a), C.R.S.

12) Each and every condition of this permit is a material part hereof and is not severable. Any challenge to or appeal of a condition hereof must constitute a rejection of the entire permit and upon such occurrence, this permit must be deemed denied *ab initio*. This permit may be revoked at any time prior to self-certification and final authorization by the Division on grounds set forth in the Colorado Air Pollution Prevention and Control Act and regulations of the AQCC including failure to meet any express term or condition of the permit. If the Division denies a

permit, conditions imposed upon a permit are contested by the applicant, or the Division revokes a permit, the applicant or owner or operator of a source may request a hearing before the AQCC for review of the Division's action. (Reference: Regulation Number 3, Part B III.F.)

13) Section 25-7-114.7(2)(a), C.R.S. requires that all sources required to file an Air Pollutant Emission Notice (APEN) must **pay an annual emission fee**. If a source or activity is to be discontinued, the owner must notify the Division in writing requesting a cancellation of the permit. Upon notification, annual fee billing will terminate.

14) Violation of the terms of a permit or of the provisions of the Colorado Air Pollution Prevention and Control Act or the regulations of the AQCC may result in administrative, civil or criminal enforcement actions under Sections 25-7-115 (enforcement), -121 (injunctions), -122 (civil penalties), -122.1 (criminal penalties), C.R.S.

ATTACHMENT A:

ALTERNATIVE OPERATING SCENARIOS

STATIONARY (CI) ENGINE

October 1, 2011

2. Alternative Operating Scenarios

The following Alternative Operating Scenario (AOS) for the temporary and permanent replacement of Stationary (CI) engines has been reviewed in accordance with the requirements of Regulation Number 3., Part A, Section IV.A, Operational Flexibility- Alternative Operating Scenarios, Regulation Number 3, Part B, Construction Permits, and Regulation Number 3, Part D, Major Stationary Source New Source Review and Prevention of Significant Deterioration, and it has been found to meet all applicable substantive and procedural requirements. This permit incorporates and shall be considered a Construction Permit for any engine replacement performed in accordance with this AOS, and the owner or operator shall be allowed to perform such engine replacement without applying for a revision to this permit or obtaining a new Construction Permit.

2.1 Engine Replacement

The following AOS is incorporated into this permit in order to deal with an engine breakdown or periodic routine maintenance and repair of an existing onsite engine that requires the use of either a temporary or permanent replacement engine. “Temporary” is defined as in the same service for 90 operating days or less in any 12 month period. “Permanent” is defined as in the same service for more than 90 operating days in any 12 month period. The 90 days is the total number of days that the engine is in operation. If the engine operates only part of a day, that day shall count as a single day towards the 90-day total. The compliance demonstrations and any periodic monitoring required by this AOS are in addition to any compliance demonstrations or periodic monitoring required by this permit.

All replacement engines are subject to all federally applicable and state-only requirements set forth in this permit (including monitoring and record keeping.

The results of any all tests and the associated calculations required by this AOS shall be submitted to the Division within 60 days. Results of all tests shall be kept on site for five (5) years and made available to the Division upon request.

The owner or operator shall maintain a log on-site and contemporaneously record the start and stop date of any engine replacement, the manufacturer, date of manufacture, model number, horsepower, and serial number of the engine(s) that are replaced during the term of this permit, and the manufacturer, model number, horsepower, and serial number of the replacement engine.

2.1.1 The owner or operator may **temporarily** replace an existing engine that is covered by this permit with a different engine without modifying this permit, so long as the temporary replacement engine complies with all permit limitations and other requirements applicable to the existing engine. Calculation of emissions from the temporary replacement engine shall be made as set forth in section 2.1.3.

2.1.2 An Air Pollutant Emissions Notice (APEN) that includes the specific manufacturer, model and serial number and horsepower of the permanent replacement engine shall be filed with the Division for the permanent replacement engine within 14 calendar days of commencing operation of the replacement engine. The APEN shall be accompanied by the appropriate APEN filing fee, a cover letter explaining that the owner or operator is exercising an alternative operating scenario and is installing a permanent replacement engine and an analysis of any new applicable requirements for the replacement engine as required by Condition 2.2. This submittal shall be accompanied by a certification from the Responsible Official indicating that "based on the information and belief formed after reasonable inquiry, the statements and information included in the submittal are true, accurate and complete".

This AOS cannot be used for permanent engine replacement of a grandfathered or permit exempt engine or an engine that is not subject to emission limits.

The owner or operator shall agree to pay fees based on the normal permit processing rate
for review of information submitted to the Division in regard to any permanent engine replacement.

2.1.3 Compliance of the replacement engine with the applicable emission limitations of the original engine shall be monitored by one of the following methods:

1) Manufacturer certified emission factors showing compliance.

2) Stack tests of same make and model showing compliance. This would only be considered if the test was done under similar conditions to Colorado (i.e. at altitude).

3) Stack tests on the engine.

2.2 Applicable Regulations for Permanent Engine Replacements

2.2.1 NSPS for stationary compression ignition internal combustion engines: 40 CFR Part 60, Subpart IIII.

A permanent replacement engine that is ordered after July 11, 2005 and manufactured after April 1, 2006 **or** is modified or reconstructed after July 11, 2005 is subject to the requirements of 40 CFR Part 60, Subpart IIII. An analysis of applicable monitoring, recordkeeping, and reporting requirements for the permanent engine replacement shall be included in any request for a permanent engine replacement.

Note that under the provisions of Regulation Number 6. Part B, section I.B. that Relocation of a source from outside of the State of Colorado into the State of Colorado is considered to be a new source, subject to the requirements of Regulation Number 6 (i.e., the date that the source is first relocated to Colorado becomes equivalent to the date of manufacture for purposes of determining the applicability of NSPS IIII requirements).

2.2.2. MACT for Stationary Reciprocating Internal Combustion Engines:40 CFR Part 63, Subpart ZZZZ.

Any permanent replacement engine located at either an area or major source is subject to the requirements of 40 CFR Part 63, Subpart ZZZZ. An analysis of applicable monitoring, recordkeeping, and reporting requirements for the permanent engine replacement shall be included in any request for a permanent engine replacement.

2.3 Additional Sources

The replacement of an existing engine with a new engine is viewed by the Division as the installation of a new emissions unit, not “routine replacement” of an existing unit. The AOS is therefore essentially an advanced construction permit review. The AOS cannot be used for additional new emission points for any site; an engine that is being installed as an entirely new emission point and not as part of an AOS-approved replacement of an existing onsite engine has to go through the appropriate Construction/Operating permitting process prior to installation.

ATTACHMENT B

PARTICULATE EMISSIONS CONTROL PLAN FOR PROCESSING ACTIVITIES

THE FOLLOWING PARTICULATE EMISSIONS CONTROL MEASURES SHALL BE USED FOR COMPLIANCE PURPOSES ON THE ACTIVITIES COVERED BY THIS PERMIT, AS REQUIRED BY THE AIR QUALITY CONTROL COMMISSION REGULATION NUMBER 1, III.D.1.b. THIS SOURCE IS SUBJECT TO THE FOLLOWING EMISSION GUIDELINES:

a. **Processing Activities -** Visible emissions not to exceed 20%, no off-property transport of visible emissions.

b. **Haul Roads -** No off-property transport of visible emissions shall apply to on-site haul roads; the nuisance guidelines shall apply to off-site haul roads.

c. **Haul Trucks -** There shall be no off-property transport of visible emissions from haul trucks when operating on the property of the owner or operator. There shall be no off-vehicle transport of visible emissions from the material in the haul trucks when operating off of the property of the owner or operator.

Control Measures

1. Plant entry way and haul roads shall be treated with chemicals for dust suppression, graveled and watered as often as needed to effectively control fugitive particulate emissions such that the above guidelines are met. Watering is not required on any day with a minimum of 0.01 inches of precipitation, when temperatures are below freezing and/or the ground is snow/ice covered, or when recent precipitation events or snow melt create a situation where such water application could create an unsafe condition for heavy equipment.

CONSTRUCTION PERMIT

Permit number: **18AC0984** **Issuance:** **1**

Date issued: February 3, 2020

Issued to: **Pagosa Forest Products, LLC**

Facility Name: Pagosa Forest Products, LLC
Plant AIRS ID: 001/0059
Physical Location: Section 4, Township 35N, Range 2W, Lot 2
County: Archuleta
General Description: Biochar production facility

Equipment or activity subject to this permit:

Facility Equipment ID	AIRS Point	Description
-	001	Biochar production unit Make: ICM, Inc., Model No. PJ003580 – Model 25 , Serial: TBD Wood is processed under low oxygen conditions to convert the wood to biochar, a charcoal like material. Off gasses generated during the process pass through a thermal oxidizer for emission control before being emitted to the atmosphere or routed to the dryer.
-	002	Wood drying Make: Player Design, Inc., Model: CFE001-630-LYT-001, Serial: TBD Fired with natural gas burners
-	004	Fugitive dust – haul roads and material handling, delivery of green wood chips and shipment of BioChar and dried wood chips. Material handling – stockpiling green wood chips, rejected green "overs" and raw material transfer to process unit, stockpiling dry wood chips, Biochar transfer and handling. BioChar transfer and handling is controlled by fabric filter(s).

Facility Equipment ID	AIRS Point	Description
Note 1: The clean wood used in the Biochar process is limited to clean lumber and wood waste only from forestry, agricultural and urban wood sources. Clean lumber and wood waste do not include wood products that have been painted, pigment-stained, or pressure treated by compounds such as chromate copper arsenate, pentachlorophenol or creosote or manufactured wood products that contain adhesives or resins (e.g. plywood, particle board, flake board and oriented strand board) or incidental debris. Painted wood in the form of trees marked with tree marking paint or lumber with similar identifying marks is allowed. Any change or addition to the type of wood used in the Biochar process will require a modification to this permit, prior to beginning use of the new wood type		

THIS PERMIT IS GRANTED SUBJECT TO ALL RULES AND REGULATIONS OF THE COLORADO AIR QUALITY CONTROL COMMISSION AND THE COLORADO AIR POLLUTION PREVENTION AND CONTROL ACT C.R.S. (25-7-101 et seq), TO THOSE GENERAL TERMS AND CONDITIONS INCLUDED IN THIS DOCUMENT AND THE FOLLOWING SPECIFIC TERMS AND CONDITIONS:

REQUIREMENTS TO SELF-CERTIFY FOR FINAL APPROVAL\

1. **YOU MUST notify the Air Pollution Control Division (Division) no later than fifteen days after commencement of operation under this permit by submitting a Notice of Startup (NOS) form to the Division.** The Notice of Startup (NOS) form may be downloaded online at https://www.colorado.gov/pacific/cdphe/other-air-permitting-notices. Failure to notify the Division of startup of the permitted source is a violation of AQCC Regulation Number 3, Part B, III.G.1 and can result in the revocation of the permit.

2. Within one hundred and eighty days (180) after commencement of operation or issuance of this permit, whichever is later, compliance with the conditions contained on this permit must be demonstrated to the Division. It is the permittee's responsibility to self certify compliance with the conditions. Failure to demonstrate compliance within 180 days may result in revocation of the permit or enforcement action by the Division. Information on how to certify compliance was mailed with the permit or can be obtained from the Division's website at https://www.colorado.gov/pacific/cdphe/air-permit-self-certification. (Reference: Regulation Number 3, Part B, III.G.2).

3. This permit will expire if the owner or operator of the source for which this permit was issued: (i) does not commence construction/modification or operation of this source within 18 months after either, the date of issuance of this construction permit or the date on which such construction or activity was scheduled to commence as set forth in the permit application associated with this permit; (ii) discontinues construction for a period of eighteen months or more; (iii) does not complete construction within a reasonable time of the estimated completion date. The Division may grant extensions of the deadline per Regulation Number 3, Part B, III.F.4.b. (Reference: Regulation Number 3, Part B, III.F.4.)

4. Point(s) 001, 002, & 004: Within one hundred and eighty days (180) after commencement of operation or issuance of this permit, whichever is later, the operator must complete all initial compliance testing and sampling as required in this permit and submit the results to the Division as part of the self-certification process. (Reference: Regulation Number 3, Part B, III.G.2.)

5. Within thirty (30) days after commencement of operation or issuance of this permit, whichever is later, the AIRS ID number must be marked on the subject equipment or posted in an

accessible location for ease of identification. (Reference: Regulation Number 3, Part B, III.E.) (State only enforceable)

6. Point(s) 001 & 002: The serial number of the subject equipment must be provided to the Division within one hundred and eighty days (180) after commencement of operation or issuance of this permit, whichever is later. (Reference: Regulation Number 3, Part B, III.G.2.)

EMISSION LIMITATIONS AND RECORDS

7. Emissions of air pollutants must not exceed the following limitations. Monthly records of the actual emission rates must be maintained by the applicant and made available to the Division for inspection upon request. (Reference: Regulation Number 3, Part B, II.A.4.)

Monthly Limits:

Facility Equipment ID	AIRS Point	Tons per Month							Emission Type
		PM	PM_{10}	$PM_{2.5}$	NO_x	SO_2	VOC	CO	
-	001	1.7	0.5	0.3	1.2	0.3	0.3	0.3	Point
-	002	2.7	1.3	0.9	0.7	0.1	1.7	0.5	Point
-	004	0.3	0.3	-	-	-	-	-	Point
-	004	0.2	0.1	-	-	-	-	-	Fugitive
TOTAL	Point	4.7	2.1	1.2	1.9	0.4	2.0	0.8	Total
	Fugitive	0.2	0.1	-	-	-	-	-	

Note: Monthly limits are based on a 31-day month.
Note: Point 004 has both fugitive and point source emissions

The owner or operator must calculate monthly emissions based on the calendar month.

Annual Limits:

Facility Equipment ID	AIRS Point	Tons per Year							Emission Type
		PM	PM_{10}	$PM_{2.5}$	NO_x	SO_2	VOC	CO	
-	001	19.7	5.9	3.9	13.5	3.2	3.7	3.7	Point
-	002	25.6	11.9	8.6	7.9	1.4	15.6	5.0	Point
-	004	3.2	3.2	0.5	-	-	-	-	Point
-	004	2.9	0.9	0.2	-	-	-	-	Fugitive
TOTAL	Point	48.5	21.0	13.0	20.4	4.6	19.3	8.7	Total
	Fugitive	2.9	0.9	0.2	-	-	-	-	

See "Notes to Permit Holder" for information on emission factors and methods used to calculate limits.

Facility-wide emissions of each individual hazardous air pollutant must not exceed 8.0 tpy.

Facility-wide emissions of total hazardous air pollutants must not exceed 20.0 tpy.

The facility-wide emissions limitation for hazardous air pollutants must apply to all permitted emission units at this facility.

During the first twelve (12) months of operation, compliance with both the monthly and annual emission limitations is required. After the first twelve (12) months of operation, compliance with only the annual limitation is required.

Compliance with the annual limits must be determined on a rolling twelve (12) month total. By the end of each month a new twelve month total is calculated based on the previous twelve months' data. The permit holder must calculate actual emissions each month and keep a compliance record on site or at a local field office with site responsibility for Division review.

The owner or operator must use the emission factors found in "Notes to Permit Holder" to calculate emissions and show compliance with the limits. The owner or operator must submit an Air Pollutant Emission Notice (APEN) and receive a modified permit prior to the use of any other method of calculating emissions.

Note: In the absence of credible evidence to the contrary, compliance with the fugitive emission limits is demonstrated by complying with the production limits listed below and by following the attached particulate emissions control plan.

8. The emission points in the table below must be maintained and operated with the control equipment as listed. The emission control devices must be inspected, monitored, maintained / renewed, and operated as per the manufacturers' recommendations, or maintained in accordance with good air pollution control practices to ensure the satisfactory performance of the devices. (Reference: Regulation Number 3, Part B, III.E.)

Facility Equipment ID	AIRS Point	Control Device	Controlled Pollutants
-	001	Thermal Oxidizer	NOx, CO, VOC
-	002	Cyclone	PM
-	004	Fabric Filter	PM

PROCESS LIMITATIONS AND RECORDS

9. This source must be limited to the following maximum consumption, processing and/or operational rates as listed below. Monthly records of the actual process rate must be maintained by the applicant and made available to the Division for inspection upon request. (Reference: Regulation Number 3, Part B, II.A.4)

Process/Consumption Limits

Facility Equipment ID	AIRS Point	Process Parameter	Annual Limit	Monthly Limit (31 days)
-	001	Dry Wood Chips	10,950 tons	930 tons
-	002	Green Wood Chips	30,000 tons	3,007 tons
-	002	Natural Gas Combusted	65.7 MMscf	5.6 MMscf

During the first twelve (12) months of operation, compliance with both the monthly and yearly process limitations must be required. After the first twelve (12) months of operation, compliance with only the yearly limitation must be required.

Compliance with the yearly process limits must be determined on a rolling twelve (12) month total. By the end of each month a new twelve-month total is calculated based on the previous twelve months' data. The permit holder must calculate monthly process rates and keep a compliance record on site or at a local field office with site responsibility, for Division review.

STATE AND FEDERAL REGULATORY REQUIREMENTS

10. Visible emissions must not exceed twenty percent (20%) opacity during normal operation of the source. During periods of startup, process modification, or adjustment of control equipment visible emissions must not exceed 30% opacity for more than six minutes in any sixty consecutive minutes. Opacity must be determined using EPA Method 9. (Reference: Regulation Number 1, II.A.1. & 4.)

11. This source is subject to the odor requirements of Regulation Number 2. (State only enforceable)

OPERATING & MAINTENANCE REQUIREMENTS

12. The owner or operator must develop an operating and maintenance (O&M) plan, along with a recordkeeping format, that outlines how the applicant will maintain compliance on an ongoing basis with the requirements of this permit. **Compliance with the O&M plan must commence at startup.** Within one hundred and eighty days (180) after commencement of operation or issuance of this permit, whichever is later, the owner or operator must submit the O&M plan to the Division. Failure to submit an acceptable operating and maintenance plan could result in revocation of the permit. Note that the Division may modify the monitoring requirements as part of the Title V Operating Permit if this facility is subject to Title V permitting (Reference: Regulation Number 3, Part B, III.G.7.).

COMPLIANCE TESTING AND SAMPLING

Initial Testing Requirements

13. Within 180 days of startup, the owner or operator must demonstrate compliance with Condition 10, using EPA Method 9 to measure opacity from the Biochar unit (point 001), the dryer (point 002) and the fabric filer controlling the biochar transfer and handling (point 004).

Sources not Subject to opacity readings of an NSPS subpart:

This measurement must consist of a minimum twenty-four consecutive readings taken at fifteen second intervals over a six minute period. (Reference: Regulation Number 1, II.A.1 & 4).

14. A source initial compliance test must be conducted on the biochar unit (point 001) and the dryer (point 002) to measure the emission rate(s) for the pollutants listed below in order to demonstrate compliance with the emission limits in this permit and the rates as submitted in the respective APENs when operating under normal conditions. The test protocol must be in accordance with the requirements of the Air Pollution Control Division Compliance Test Manual and must be submitted to the Division for review and approval at least thirty (30) days prior to testing. No compliance test must be conducted without prior approval from the Division. Any compliance test conducted to show compliance with a monthly or annual emission limitation must have the results projected up to the monthly or annual averaging time by multiplying the test results by the allowable number of operating hours for that averaging time (Reference: Regulation Number 3, Part B., III.G.3)

Particulate Matter using EPA approved methods from biochar and dryer units.

Sulfur Dioxide using EPA approved methods from biochar and dryer units.
Oxides of Nitrogen using EPA approved methods from biochar and dryer units.
Volatile Organic Compounds using EPA approved methods from biochar unit.
Carbon Monoxide using EPA approved methods from biochar and dryer units.

Periodic Testing Requirements

15. There are no periodic testing requirements.

ADDITIONAL REQUIREMENTS

16. The AIRS ID number must be marked on the subject equipment or posted in an accessible location for ease of identification. (Reference: Regulation Number 3, Part B, III.E.) (State only enforceable)

17. Public access must be precluded in all areas within the modeling receptor exclusion zone as submitted with the modeling in the application. The exclusion zone must be fenced and posted with no trespassing signs. The source must maintain continuous fencing along the boundary depicted in Diagram 7 in Appendix B of the October 2019 submittal "Air Quality Dispersion Modeling Report for Pagosa Forest Products, LLC." and attached to this report (Appendix A). (Reference: Regulation Number 3, Part B, III.B.5)

18. Stack Heights - Modeled impacts were estimated assuming the stack heights indicated release height in Table 2 of the November 2019 submittal "Air Quality Dispersion Modeling Report for Pagosa Forest Products, LLC." and attached to this report (Appendix B). For the duration of the permit effectiveness the exhaust from each emission unit shall be discharged above ground level at the stack heights listed in the aforementioned table. In addition all stacks listed in that table shall be unobstructed and vertically upward, with the exception of the Biochar/TO stack, which will be obstructed with a rain cap and spark arrestor.

19. A Revised Air Pollutant Emission Notice (APEN) must be filed: (Reference: Regulation Number 3, Part A, II.C.)

    a. By April 30 of the year following a significant increase in emissions. A significant increase in emissions is defined as follows:

       For any criteria pollutant:

       For sources emitting **less than 100 tons per year**, a change in actual emissions of five tons per year or more, above the level reported on the last APEN submitted; or

       For volatile organic compounds (VOC) and nitrogen oxide (NOx) sources in an ozone non-attainment area emitting **less than 100 tons of VOC or nitrogen oxide per year**, a change in actual emissions of one ton per year or more or five percent, whichever is greater, above the level reported on the last APEN submitted; or

       For sources emitting **100 tons per year or more of a criteria pollutant**, a change in actual emissions of five percent or 50 tons per year or more, whichever is less, above the level reported on the last APEN submitted; or

       For sources emitting **any amount of lead**, a change in actual emissions, above the level reported on the last APEN submitted, of fifty (50) pounds of lead

       For any non-criteria reportable pollutant:

If the emissions increase by 50% or five (5) tons per year, whichever is less, above the level reported on the last APEN submitted to the Division.

b. Whenever there is a change in the owner or operator of any facility, process, or activity; or

c. Whenever new control equipment is installed, or whenever a different type of control equipment replaces an existing type of control equipment; or

d. Whenever a permit limitation must be modified; or

e. No later than 30 days before the existing APEN expires.

GENERAL TERMS AND CONDITIONS:

20. This permit and any attachments must be retained and made available for inspection upon request. The permit may be reissued to a new owner by the Division as provided in Regulation Number 3, Part B, II.B upon a request for transfer of ownership and the submittal of a revised APEN and the required fee.

21. If this permit specifically states that final approval has been granted, then the remainder of this condition is not applicable. Otherwise, the issuance of this construction permit is considered initial approval and does not provide "final" approval for this activity or operation of this source. Final approval of the permit must be secured from the APCD in writing in accordance with the provisions of 25-7-114.5(12)(a) C.R.S. and AQCC Regulation Number 3, Part B, III.G. Final approval cannot be granted until the operation or activity commences and has been verified by the APCD as conforming in all respects with the conditions of the permit. Once self-certification of all points has been reviewed and approved by the Division, it will provide written documentation of such final approval. **Details for obtaining final approval to operate are located in the Requirements to Self-Certify for Final Approval section of this permit.** The operator must retain the permit final approval letter issued by the Division after completion of self-certification with the most current construction permit.

22. This permit is issued in reliance upon the accuracy and completeness of information supplied by the applicant and is conditioned upon conduct of the activity, or construction, installation and operation of the source, in accordance with this information and with representations made by the applicant or applicant's agents. It is valid only for the equipment and operations or activity(ies) specifically identified in this permit. If subsequent operations or testing at the source indicate the information supplied to obtain this permit and relied upon in the creation and issuance of this permit is inaccurate, the source must submit an application to modify the permit to address the inaccuracy(ies). (Reference: Regulation Number 3, Part B III.E.)

By: Aaron Moseley
Aaron Moseley
Permit Engineer

By: R K Hancock III
R K Hancock III, P.E.
Construction Permits Unit Supervisor

Permit History

Issuance	Date	Description
Issuance #1	This Issuance	Initial approval issued to Pagosa Forest Products, LLC.

Notes to Permit Holder (as of date of permit issuance):

1) The production or raw material processing limits and emission limits contained in this permit are based on the production/processing rates requested in the permit application. These limits may be revised upon request of the permittee providing there is no exceedence of any specific emission control regulation or any ambient air quality standard. A revised air pollutant emission notice (APEN) and application form must be submitted with a request for a permit revision. (Reference: Regulation Number 3, Part B II.A.4.)

2) This source is subject to the Common Provisions Regulation Part II, Subpart E, Affirmative Defense Provision for Excess Emissions During Malfunctions. The permittee must notify the Division of any malfunction condition which causes a violation of any emission limit or limits stated in this permit as soon as possible, but no later than noon of the next working day, followed by written notice to the Division addressing all of the criteria set forth in Part II.E.1. of the Common Provisions Regulation. See: https://www.colorado.gov/pacific/cdphe/aqcc-regs.

3) The following emissions of non-criteria reportable air pollutants are estimated based upon the process limits as indicated in this permit. This information is listed to inform the operator of the Division's analysis of the specific compounds emitted if the source(s) operate at the permitted limitations.

AIRS Point	Pollutant	CAS #	Uncontrolled Emission Rate (lb/yr)	Are the emissions reportable?	Controlled Emission Rate (lb/yr)
001 & 002	Methanol	67561	147,200	YES	7,360
	Hydrogen Chloride	7647010	45,600	YES	2,280

4) The emission levels contained in this permit are based on the following emission factors:

Point 001:

CAS	Pollutant	Emission Factors (lbs/ton of dry wood chips)		
		Uncontrolled	Controlled	Source
	PM	-	3.600	Vendor
	PM10	-	1.080	Vendor
	PM2.5	-	0.7204	Vendor
	NO_x	-	2.464	Vendor
	SO_2	-	0.592	Vendor
5000	CO	-	0.6720	Vendor
75070	VOC	-	0.6720	Vendor

Point 002:

		Emission Factors (lbs/ton of green wood chips)

COLORADO
Air Pollution Control Division
Department of Public Health & Environment

CAS	Pollutant	Uncontrolled	Controlled	Source
	PM	-	1.7252	Vendor
	PM10	-	0.8064	Vendor
	PM2.5	-	0.5894	Vendor
	NO_x	-	0.7464	Vendor
	SO_2	-	0.0923	Vendor
5000	CO	-	1.0504	Vendor
75070	VOC	-	0.5183	Vendor

5) In accordance with C.R.S. 25-7-114.1, each Air Pollutant Emission Notice (APEN) associated with this permit is valid for a term of five years from the date it was received by the Division. A revised APEN must be submitted no later than 30 days before the five-year term expires. Please refer to the most recent annual fee invoice to determine the APEN expiration date for each emissions point associated with this permit. For any questions regarding a specific expiration date call the Division at (303)-692-3150.

6) This facility is classified as follows:

Applicable Requirement	Status
Operating Permit	Synthetic Minor Source: PM, PM10, PM2.5, NOx, HAPs Minor Source: SO2, CO, VOC
PSD	Synthetic Minor Source: PM, PM10, PM2.5, NOx Minor Source: SO2, CO, VOC

7) The permit holder is required to pay fees for the processing time for this permit. An invoice for these fees will be issued after the permit is issued. Failure to pay the invoice will result in revocation of this permit. The permit holder must pay the invoice within 30 days of receipt of the invoice (Reference: Regulation Number 3, Part A, VI.B.).

8) Unless specifically stated otherwise, the general and specific conditions contained in this permit have been determined by the Division to be necessary to assure compliance with the provisions of Section 25-7-114.5(7)(a), C.R.S.

9) Each and every condition of this permit is a material part hereof and is not severable. Any challenge to or appeal of a condition hereof must constitute a rejection of the entire permit and upon such occurrence, this permit must be deemed denied *ab initio*. This permit may be revoked at any time prior to self-certification and final authorization by the Division on grounds set forth in the Colorado Air Pollution Prevention and Control Act and regulations of the AQCC including failure to meet any express term or condition of the permit. If the Division denies a permit, conditions imposed upon a permit are contested by the applicant, or the Division revokes a permit, the applicant or owner or operator of a source may request a hearing before the AQCC for review of the Division's action. (Reference: Regulation Number 3, Part B III.F.)

10) Section 25-7-114.7(2)(a), C.R.S. requires that all sources required to file an Air Pollutant Emission Notice (APEN) must **pay an annual emission fee**. If a source or activity is to be discontinued, the owner must notify the Division in writing requesting a cancellation of the permit. Upon notification, annual fee billing will terminate.

11) Violation of the terms of a permit or of the provisions of the Colorado Air Pollution Prevention and Control Act or the regulations of the AQCC may result in administrative, civil or criminal enforcement actions under Sections 25-7-115 (enforcement), -121 (injunctions), -122 (civil penalties), -122.1 (criminal penalties), C.R.S.

PARTICULATE EMISSIONS CONTROL PLAN FOR MINING AND PROCESSING ACTIVITIES

THE FOLLOWING PARTICULATE EMISSIONS CONTROL MEASURES MUST BE USED FOR COMPLIANCE PURPOSES ON THE ACTIVITIES COVERED BY THIS PERMIT, AS REQUIRED BY THE AIR QUALITY CONTROL COMMISSION REGULATION NUMBER 1, III.D.1.b. THIS SOURCE IS SUBJECT TO THE FOLLOWING EMISSION GUIDELINES:

a. **Mining and Processing Activities -** Visible emissions not to exceed 20%, no off-property transport of visible emissions.

b. **Haul Roads -** No off-property transport of visible emissions must apply to on-site haul roads, the nuisance guidelines must apply to off-site haul roads.

c. **Haul Trucks -** There must be no off-property transport of visible emissions from haul trucks when operating on the property of the owner or operator. There must be no off-vehicle transport of visible emissions from the material in the haul trucks when operating off of the property of the owner or operator.

Control Measures

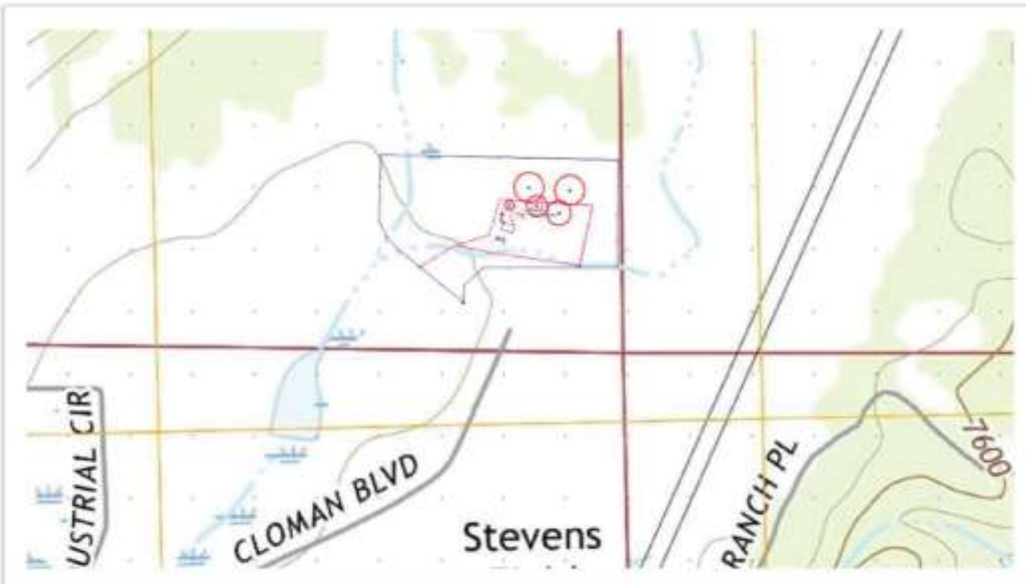
1. Vehicle speed on unpaved roads and disturbed areas must not exceed a maximum of 10 miles per hour. Speed limit signs must be posted.

2. Material stockpiles must be watered as necessary to control fugitive particulate emissions.

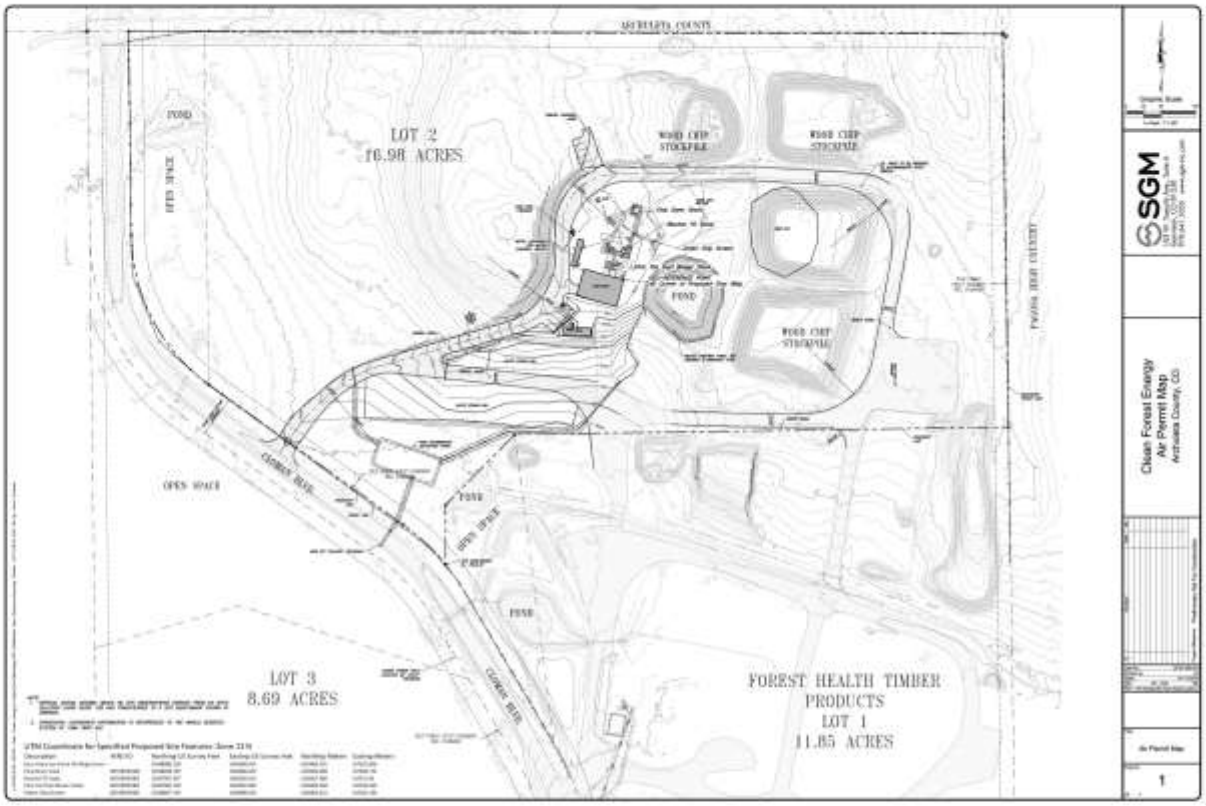
3. Modeled impacts were estimated assuming that the operations of the Haul Roads assume double traffic in a 24-hr period for the Biochar and Wood chip delivery. The number of trucks are restricted to: 13 Green chips, 6 Wood chips and 5 Biochar per day, as this is how emissions were modeled. Daily records of the actual process rate must be maintained by the applicant and made available to the Division for inspection upon request.

4. Haul roads must be watered as often as needed to control fugitive particulate emissions such that the above guidelines are met.

Appendix A
FENCING AND PRECLUSION OF PUBLIC ACCESS



Pagosa Forest Products, LLC
Modeled Layout - USGS 1:24,000-scale
Source View


ARCHULETA COUNTY
LOT 2
16.98 ACRES
WOOD CHIP STOCKPILE
POND
OPEN SPACE
LOT 3
8.69 ACRES
FOREST HEALTH TIMBER
PRODUCTS
LOT 1
11.85 ACRES
SGM
Clean Forest Energy
Air Permit Map
Archuleta County, CO
1

APPENDIX B

UNIT	HEIGHT (FT)	DIAMETER (FT)	EXHAUST FLOW (FT^3/MIN)	TEMPERATURE (F)	DESCRIPTION
BIOCHAR / TO	32.7	4.325	20,140	900	VERTICAL, OBSTRUCTED: RAIN CAP & SPARK ARRESTOR
WOOD CHIP DRYER	20	1.78	13,853	185	VERTICAL, UNOBSTRUCTED
CHAR VAC DUST BLOWER	20*	1.0**	4,250	AMBIENT	VERTICAL, UNOBSTRUCTED

*ONLY CHANGE TO APCD'S MODELING INPUT FILES

** THE STACK WILL BE SQUARE; THE 1.0 DIAMETER IS THE EQUIVALENT CIRCULAR DIAMETER OF A SQUARE WITH POSED ARE OF 0.785 FT^2.

Financial Performance of a Mobile Pyrolysis System Used to Produce Biochar from Sawmill Residues

Dongyeob Kim
Nathaniel McLean Anderson
Woodam Chung

Abstract

Primary wood products manufacturers generate significant amounts of woody biomass residues that can be used as feedstocks for distributed-scale thermochemical conversion systems that produce valuable bioenergy and bioproducts. However, private investment in these technologies is driven primarily by financial performance, which is often unknown for new technologies with limited industrial deployment. In this paper, we use shift-level production data collected during a 25-day field study to characterize the conversion rate and system productivity and costs for a commercially available pyrolysis system co-located at a sawmill, and then evaluate the net present value (NPV) of the operation in light of a cost structure that is realistic for the industry. Baseline costs on a feedstock throughput basis were estimated as \$16.41 t^{-1} for feedstock preparation, \$308.14 t^{-1} for conversion, and \$65.99 t^{-1} for biochar bagging. The NPV estimated for the worst-case scenario of observed productivity and conversion rate was –\$536,031 for a 10-year project period, while the best case scenario generated an NPV of \$467,353. In general, NPV is highly sensitive to labor costs and biochar price, and less sensitive to fuel cost and interest rate. Results also show clear opportunities for technical and operational improvements that are expected to increase the financial viability of this system.

Sawmills and other wood products manufacturers produce large quantities of woody biomass in the form of wood chips, sawdust, shavings, and bark. These by-products, also called mill residues, are commonly sold as raw material for the manufacture of paper and engineered wood panels (e.g., clean chips for pulp and sawdust for particle board), for landscaping applications (e.g., bark mulch), and as fuel for combustion boilers (e.g., hog fuel). Over the last decade, permanent closures of paper and panel mills in the interior western United States have decreased the regional demand for mill residues. As a result, sawmills in this region often haul residues long distances to market, sometimes hundreds of miles. In general, higher transportation costs resulting from low local and regional demand for residues negatively impact the financial viability of solid wood products manufacturing by reducing revenues and potentially turning previously marketable by-products into waste materials with disposal costs.

The use of biochemical or thermochemical biomass conversion technologies to produce liquid fuels, chemicals, and other high-value bioproducts has been proposed as a solution to this problem (Badger and Fransham 2006, Briens et al. 2008). Depending on the feedstock used and the substitutability of end products, these outputs have potential to offset fossil fuel use and associated emissions with renewable forest resources. Furthermore, they can improve energy security by displacing imported fuels and petrochemicals with domestic biomass energy products. These benefits potentially apply to a broad range of market products made from woody biomass, including torrefied wood (Uslu et al. 2008), charcoal and biochar (Antal and Gronli 2003, Anderson et al. 2013), ethanol (Duff and Murray 1996), methanol (Hamelinck and Faaij 2006), bio-oil (Bridgewater 2004, Mohan et al. 2006), and producer gas used for heat and power or as chemical feedstock (i.e.,

The authors are, respectively, Research Scientist, Dept. of Forest Conservation, Korea Forest Research Inst. (KFRI), Seoul, Republic of Korea (South Korea) (dykim.forest@korea.kr); Research Forester, Rocky Mountain Research Sta., USDA Forest Service, Missoula, Montana (nathanielmanderson@fs.fed.us [corresponding author]); and Associate Professor and Stewart Professor of Forest Engineering, College of Forestry, Oregon State Univ., Corvallis (woodam.chung@oregonstate.edu). This paper was received for publication in May 2014. Article no. 14-00052.

Forest Prod. J. 65(5/6):189–197.
doi:10.13073/FPJ-D-14-00052

synthesis gas; Bridgewater 2003). In some cases, the primary products of conversion can serve as intermediates in the production of drop-in liquid fuels, chemicals, and other industrial products, including activated carbon (Azargohar and Dalai 2006), Fischer–Tropsch liquids (Tijmensen et al. 2002), and organic distillates (Briens et al. 2008). Some of these products have well-established markets (e.g., ethanol and activated carbon), while others are characterized by nascent and emerging markets (e.g., biochar and bio-oil).

A large body of research is devoted to laboratory and pilot-scale study of thermochemical conversion of woody biomass (Mohan et al. 2006, Kumar et al. 2009, van der Stelt et al. 2011), and an increasing number of companies are developing and marketing commercial technologies for biomass conversion. At least several companies manufacture distributed-scale conversion systems, and some have marketed these systems for forest biomass processing (e.g., Biochar Solutions Inc. [BSI] 2011, PHG Energy 2011). Furthermore, a small but growing body of research is being developed to guide the optimization of supply chain logistics for distributed-scale forest biomass processing and production, especially through techno-economic analysis (e.g., Brown et al. 2013).

As this industry evolves across multiple agricultural, forestry, and waste management sectors, there are at least three operational characteristics of thermochemical conversion systems that are spurring interest by the forest industry, in addition to the potential environmental and economic benefits of products derived from woody biomass. First, these systems can be configured to produce heat and power for mill operations, in addition to liquid and solid products that can be shipped to distant markets. Second, these technologies are scalable. Distributed-scale systems and their mobility have the potential to allow individual firms to match their residue streams with appropriate conversion capacity. Finally, in contrast to a biorefinery model using a biochemical conversion pathway such as fermentation or anaerobic digestion, thermochemical systems are more similar to the traditional biomass combustion systems that are already widely deployed in the industry, making them appear less risky from an operational standpoint.

For forest industry firms, the decision to invest in a thermochemical conversion system for processing residues hinges on the cost structure and financial performance of such an operation. Unfortunately, there is a high degree of uncertainty related to the performance of these systems and little market data to support selling their outputs, especially for biochar and bio-oil. This is primarily due to the fact that distributed pyrolysis systems are not yet widely deployed in industrial settings, resulting in a lack of economic data and market transactions for products. Existing studies tend to rely on theoretical production estimates based on engineering specifications and short laboratory and field trials rather than empirical data collected during manufacturing operations (e.g., Sorenson 2010, Badger et al. 2011, Brown et al. 2011). To our knowledge, prior to this work, no study examined the use of distributed-scale thermochemical conversion using operations research methods (i.e., work study) to quantify costs, productivity, and financial performance.

The objective of this study was to evaluate a commercially available system in the context of co-locating with forest industry operations. Objectives included: (1) observation of a mobile pyrolysis reactor operating at a sawmill in Colorado, (2) collection of shift-level production data to characterize conversion rate and system productivity and costs, and (3) evaluation of the net present value (NPV) of the operation in light of a cost structure that is realistic for the industry. This new knowledge is needed by technology firms, investors, and managers to evaluate the potential costs and benefits of integrating distributed-scale thermochemical processing systems into existing operations.

Methods

Biomass conversion using mobile pyrolysis

Thermochemical conversion can occur across broad ranges of temperature, pressure, heating rate, oxidation conditions, and residence time. The Biochar Solutions Inc. pyrolysis system (BSI, Carbondale, Colorado) used in this study was engineered to produce biochar from biomass including agricultural residues and wood waste (Fig. 1). This small-scale mobile pyrolysis system produces biochars with high fixed carbon content and high sorption using an exothermic reaction at temperatures between 350°C and 750°C (Anderson et al. 2013). Gas and heat are generally considered co-products of biochar production. Though a fraction of the gas stream could technically be condensed into bio-oil, the system does not produce a liquid output.

The BSI system uses a two-stage reactor. In the primary reactor, the feedstock is carbonized in a controlled aerobic environment with limited oxygen at a temperature between 700°C and 750°C for less than 1 minute. Then the material passes into a second reactor, where material is held in a sweep gas environment for approximately 10 to 15 minutes at a temperature between 400°C and 550°C before it is removed from the machine by a liquid cooled auger with an air lock. The dust fraction of biochar present in the gas stream is collected by a cyclone trap before the gas is evacuated from the system by a blower. Dust does not receive the same sweep gas treatment as the coarse biochar output, which receives full residence time in the second reactor. The gas produced during the first stage of pyrolysis is used as sweep gas for the second stage and is pulled through the system by a blower. This gas is composed primarily of carbon monoxide, nitrogen, methane, and hydrogen, with some oxygen. Some limited oxidation occurs in the first stage, but oxidation is very low in the second stage.

Figure 1.—The Biochar Solutions Inc. mobile pyrolysis system field-deployed and evaluated in this study.

Data collection and productivity study

A system productivity study was designed to evaluate the production and financial performance of a BSI mobile pyrolysis system deployed at a sawmill in Pueblo, Colorado. Data collection was carried out at the site for 25 working days in October and November, 2011. Two different types of mill residues were used as feedstock in thermochemical biomass conversion: green mixed conifer mill residues and beetle-killed mill residues. Mixed conifer mill residues were composed of ponderosa pine (*Pinus ponderosa* Douglas ex C. Lawson, 90% by mass) and other conifer tree species (10%), such as Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Beetle-killed mill residues were produced from beetle-killed lodgepole pine (*Pinus contorta* Douglas). Debarked logs with a minimum small-end diameter of 15 cm were harvested in October 2011, from the White River National Forest in northwest Colorado (39°34′3″N, 106°51′41″W), delivered to the mill, and sawn into lumber. The resultant edge slabs and other mill residues were chipped at the mill site, and then preprocessed by grinding and screening to a particle size of less than 7.62 cm in the longest dimension. The average moisture content of the resultant feedstocks measured in the laboratory was 9.89 percent for mixed conifer feedstocks and 15.78 percent for beetle-killed feedstocks at the time of conversion. This moisture content includes the effects of pre-conversion drying on the conveyor, which passes through hot gasses in the exhaust stack (Fig. 1).

The BSI pyrolysis system was operated by either one or two operators in one 8-hour shift per day during the 25-day study period. The system was started in the morning by turning on the blower and initiating combustion in the first stage reactor with a propane torch. After startup, system operation typically included four steps: feedstock loading, feedstock conveying and drying, thermochemical conversion, and biochar collection (Fig. 2). First, a front-end wheeled loader is used to load preprocessed feedstock into a hopper. Feedstock is then slowly moved into the reactor through a conveyor system, while being dried by heat generated from the thermal oxidizer exhaust stack. The two-stage reactor converts feedstock into biochar, and finally biochar is collected into barrels in two different forms: coarse biochar from a liquid cooled auger and dust removed from the gas stream by a cyclone. Feedstock loading occurred only when the hopper was almost empty, while the other operations took place simultaneously during productive operation.

To estimate the system productivity, shift-level time study data were collected during operation and included start time, end time, weather conditions, and delays. Start time was measured when the system blower was turned on at the beginning of each shift, and end time was measured when the entire system was shut down and the operators left the site. All delays during operation were recorded and described, and delay time was removed from scheduled machine hours to calculate delay-free productive machine time. Delays were defined as any break times longer than 10 minutes in blower operation, with an assumption that the system does not produce biochar when the blower is off. This assumption is based on the design of the two-stage reactor, which uses blower pressure to evacuate biochar from the reactor body. Delays recorded include operational delays (e.g., empty feedstock hopper), mechanical delays (e.g., maintenance and repair), and operator delays (e.g., meal time). To estimate system productivity and conversion rate on a per unit weight basis, the total weight of feedstock was measured using an in-ground certified platform truck scale at the site to weigh feedstock at the beginning of each shift, and the weights of biochar chips and dust output in barrels were measured using an electronic floor scale. In addition, the pressure and temperature of reactors and gas-paths of the BSI system were monitored and recorded with a computer during the operation.

Estimating productivity and conversion rate

Productivity and biochar conversion rate are important measures of pyrolysis system performance. In this study, shift-level productivity is defined as a ratio of the amount of feedstock consumed during the shift in green tonnes (t) to productive machine hours (h). Gross level productivity of the system (t h^{-1}) then can be estimated by compiling shift-level data for the entire field study period. Productivity is calculated on a productive machine time basis, which does not include delay, not on a scheduled machine time basis, which does include delay. The ratio of productive time to scheduled time is known as the utilization rate, and is typically quantified using long-term production data. The BSI pyrolysis system used in this study is an early design, and stable utilization rates have not been established for the system. Because productivity on a productive machine time basis provides delay-free productivity, it is often considered an appropriate productivity measure for machines in an early stage of development, and can be used with generalized equipment utilization rates to estimate productivity on a scheduled machine time basis (Miyata 1980, Olsen et al. 1998). For example, in the baseline case scenario described below, the assumed utilization rate for equipment is 80 percent.

In addition, in this study the productivity measure is based on the amount of feedstock consumption rather than biochar production because several cost factors considered in the financial analysis depend on feedstock characteristics, such as feedstock loading and preprocessing costs, and because feedstock throughput is an important metric when

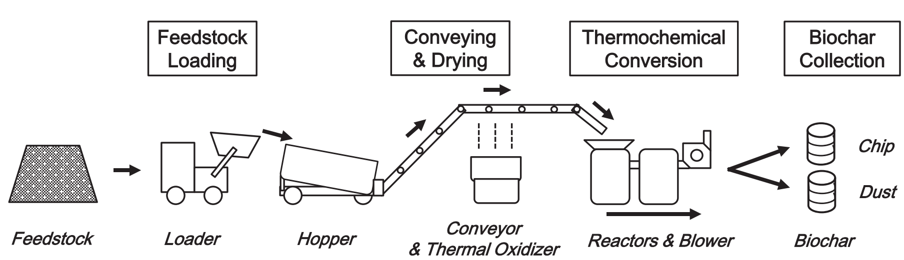


Figure 2.—Operational steps to convert mill residues into biochar using the Biochar Solutions Inc. pyrolysis system.

considering pyrolysis systems for management of biomass by-products, including mill residues. Conversion rate was defined as a mass ratio of the total biochar produced to the total feedstock consumed during production. The total amount of biochar produced includes biochar chips and dust, which are both marketable products of the operation.

Calculating machine rates and operation costs

Pyrolysis system costs are estimated on a dollar per green tonne of feedstock basis using costs broken into three categories: feedstock preparation, pyrolysis conversion, and biochar bagging (Fig. 3). Feedstock preparation includes feedstock grinding, screening, and loading operations. Each operation requires the use of machinery, such as a tub grinder, rotary screener, loader, pyrolysis system, and biochar bagging equipment. The cost of each operation can then be estimated using a standardized machine hourly cost (i.e., machine rate) required for the operation, and machine productivity (Eq. 1).

$$\text{Cost}\,(\$\,t^{-1}) = \text{Machine rate}\,(\$\,h^{-1})/\text{Productivity}\,(t\ h^{-1}) \quad (1)$$

Widely accepted standard methods for machine rate calculations were used to calculate machine rates for individual machines used in the pyrolysis operation (Brinker et al. 2002). Machine rate parameters for a tub grinder and a wheel loader were obtained from the default values suggested in the Forest Residue Trucking Simulator v 5.0 (FoRTS v 5.0; US Department of Agriculture [USDA] 2005), while the price of the screener was obtained from the machine owner (Table 1). For the BSI pyrolysis system, most machine rate parameters in Table 1 were obtained from the manufacturer's suggestions except for the productive machine hours per year of the machine. The machine is assumed to operate productively for 8 h/d and 260 d/y. The purchase price of the BSI mobile U5 beta unit of $350,000 (Table 1) includes a $9,880 initial setup cost, which includes $5,000 transportation of the unit to the site, $2,400 in setup labor, $1,480 in administration and overhead, and $1,000 in electrical work, with all cost estimates provided by the manufacturer.

For machine productivity, the default values from FoRTS v.5 were used for a tub grinder and a wheel loader, which are 13.608 t h^{-1} and 54.432 t h^{-1}, respectively. For the screening equipment, a productivity of 13.608 t h^{-1} was used as the operator's estimate, based on the fact that the screener has a higher productivity than the tub grinder and is therefore constrained by grinder productivity. The productivity of the BSI pyrolysis system observed during the field study was used in the cost calculation.

Unlike the aforementioned cost calculations using machine rates and productivity, biochar bagging costs were estimated based on the pyrolysis system owner's suggestion, which was $52.31 m^{-3} for bagging operation costs and $10 for each 0.76 m^{-3} bulk bag. To be consistent with other cost measures, these bagging operations costs were converted into dollars per green tonne of feedstock using the conversion rate and biochar density observed during the field study.

Analyzing financial performance

To evaluate the financial performance of the pyrolysis operation, yearly cash flows for an assumed 10-year project period were developed and NPV was calculated based on a 7 percent real interest rate (i.e., discount rate). Using a riskless real rate of 3.0 percent that includes a nominal rate of 2.5 percent and a long-term average rate of inflation of 0.5 percent, this rate includes an implied risk premium of 4 percent. Our interest rate of 7 percent falls between the 3.75 percent rate that Federal agencies use for natural resources projects (US Federal Register 2013) and the 10 percent rate commonly used in techno-economic studies of larger scale projects (Anex et al. 2010, Wright et al. 2010, Davis et al. 2011). We chose a 4 percent risk premium in this case to quantify risks in both production and product marketing, with biochar being produced for nascent, negotiated spot markets by an emerging technology, rather than a lower rate that might be used for a project supplying commodity markets using a proven commercial technology.

All monetary values are presented as 2011 US dollars ($). It was assumed that sale of biochar was the only revenue source and that both biochar chips and dust were sold at the same price. Though it is possible to use producer gas combustion as a heat source for lumber drying and heat treating products to kill insects before export, the value of the producer gas is assumed to be zero in this analysis because the system was not configured for this use at the time of field data collection.

A market price for biochar of $2.2 kg^{-1} for mine reclamation soil amendment markets near the study site was used in the analysis after being converted into dollars per green tonne of feedstock value ($ t^{-1}). This price does not include any monetary value related to carbon sequestration in the soil, which has been identified as a potential source of revenue for biochar projects (Galinato et al. 2011), because this value was not monetized at the time of the study. The value of feedstock prior to feedstock processing was considered to be zero because the mill residues used in pyrolysis conversion were considered to be a by-product with neither disposal costs nor alternative markets (e.g., pulp) that would generate net revenue.

Sensitivity analyses were conducted to evaluate the sensitivity of financial performance (i.e., NPV) of the pyrolysis operation to cost and revenue variables, such as wages, fuel cost, interest rate, and biochar market price. The range of each variable from –30 to +30 percent of the baseline value was used in the sensitivity analyses while the other variables remained constant. Analyses were also conducted to identify the value of each variable that resulted in an NPV of zero, holding all other variables constant at the baseline value. For the interest rate, the value that makes the NPV equal to zero is known as the internal rate of return

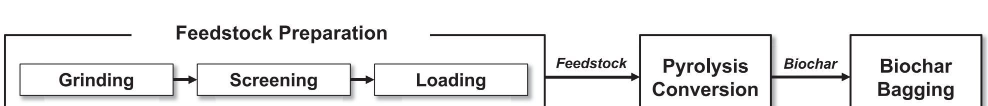


Figure 3.—Cost elements of the entire pyrolysis operation from feedstock preparation to packaging the final product.

Table 1.—Machine rate parameters used in calculating hourly cost of machine with operator.

Parameter	Grinding (tub grinder)	Screening (rotary screener)	Loading (wheel loader)	Pyrolysis (BSI mobile U5 beta)
Purchase price ($)	350,000	50,000	205,000	350,000
Productive machine hours (h y^{-1})	1,664	1,664	1,664	2,080
Scheduled machine hours (h y^{-1})	2,080	2,080	2,080	NA[a]
Utilization rate (%)	80	80	80	NA
Machine life (y)	7	7	7	10
Salvage (% of price)	20	20	20	10
Interest (%)	7	7	7	7
Fuel cost ($ L^{-1})	0.85	0.85	0.85	NA
Electricity cost ($ MJ^{-1})	NA	NA	NA	0.02
Hourly labor wage ($)	17.89	17.89	17.89	17.89
Labor benefits (%)	35	35	35	35

[a] NA = not applicable.

(IRR), which is a measure of how fast the investment grows. In financial analysis, an NPV of zero generally indicates the threshold of an economically desirable project because it includes an established rate of return (7% in our baseline case, for example). In addition, sensitivity analyses of financial performance to the pyrolysis system's productivity and conversion rate were performed to assess the potential benefits from machine improvements that would result in a stable biochar production rate. The empirical ranges of productivity and conversion rate observed during the field study were used in these sensitivity analyses.

Results

BSI pyrolysis system productivity

During a total of 25 days of field study, the pyrolysis system was productive for 22 days and undergoing maintenance for 3 days due to unexpected mechanical problems. As with other delays, this unexpected maintenance period is not included in the productivity analysis because we used delay-free productive machine time. Total hours worked during 22 working days were 167.0 hours ranging from 3.8 to 10.2 hours per working day or an average of 7.6 hours per shift (Table 2). Hours worked in each shift varied depending on operators' working schedules, pyrolysis system performance, and weather conditions. The system operated in the open, and was not operated during heavy rain or snow. There were a total of 31.4 hours of delays recorded during 22 working days with an average of 1.4 hours of delay per shift. The highest proportion of delay time was attributed to mechanical delay caused by problems such as reactor clogging and auger malfunction, but operational and personal delays are also included in this total. For comparison to the 80 percent utilization rate applied to feedstock preparation equipment, the observed utilization rates for the pyrolysis system including and excluding the 3-day maintenance period were 75.1 and 84.2 percent, respectively. However, as discussed previously, the design and duration of this study make it inappropriate for measuring utilization rate.

A total of 21.2 t of feedstock were consumed during the field study, while a total of 3.0 t of biochar were produced, for an observed conversion rate of 14.1 percent by mass. The biochar production amount in Table 2 includes both biochar chips and dust. During the field study, weight of biochar chips produced was measured at the end of each shift, but biochar dust was measured only when the dust-collecting barrel was removed from the system and replaced, normally once every two to three shifts. To estimate the shift-level biochar dust production, the ratio of dust to chips was calculated using the gross amount of production of each product, and then shift-level biochar chip production was multiplied by the resultant ratio (0.315).

Based on the observed gross feedstock consumption and productive work hours over the 22 working days, the productivity of the BSI pyrolysis system is estimated as 0.156 t h^{-1} (Table 2). The shift-level productivity ranged from 0.114 to 0.219 t h^{-1}.

Machine rates and costs of pyrolysis operation

Machine rates estimated for a tub grinder, a rotary screener, and a wheel loader used for feedstock preparation were $163.81, $39.78, and $78.86 h^{-1}, respectively (Table 3). The machine rate of the BSI pyrolysis system was $48.07 h^{-1}. Total feedstock preparation costs were estimated as $16.41 t^{-1} of feedstock. Among the three individual operations of feedstock preparation, grinding was the most expensive component, accounting for 73 percent of the total feedstock preparation costs. The cost of pyrolysis conversion using the BSI system was estimated as $308.14 t^{-1}

Table 2.—Summary statistics of the shift-level production data.

Statistic	Shift time (h)	Delay time (h)	Productive work time (h)	Feedstock consumed (t)	Biochar production (t)
Total	167.03	31.35	135.68	21.183	2.993
Shift-level					
Mean	7.59	1.43	6.17	0.963	0.136
Min.	3.75	0	2.23	0.219	0.041
Max.	10.23	5.3	9.2	1.433	0.285

Table 3.—Pyrolysis operation costs estimated on a green tonne (t) of feedstock basis.

	Feedstock preparation				
	Grinding	Screening	Loading	Pyrolysis	Biochar bagging
Machine rate ($ h^{-1})	163.81	39.78	78.86	48.07	NA[a]
Productivity (t h^{-1})	13.608	13.608	54.432	0.156	NA
Cost ($ t^{-1})	12.04	2.92	1.45	308.14	65.99

[a] NA = not applicable

based on the system machine rate and observed system productivity (Table 3). Biochar bagging cost was estimated as \$65.99 t^{-1}. In the bagging cost calculation, a biochar density of 0.141 Mg m^{-3} (Anderson et al. 2013) and a conversion rate of 14.1 percent were used. In summary, the total cost of the entire pyrolysis operation for biomass-to-biochar conversion was estimated as \$390.54 t^{-1} of feedstock, and the conversion process was the most expensive component of the operation, accounting for 79 percent of the total cost.

Financial performance

Using the operational cost estimation and the cost structure and assumptions used in the baseline case, including a 7 percent interest rate, an annual total cost was estimated as \$126,567 including \$5,295 for feedstock preparation, \$99,976 for pyrolysis conversion, and \$21,296 for biochar bagging. Annual revenue from biochar was \$101,013 for the baseline case, resulting in an NPV of –\$168,955 for a 10-year project period.

Figure 4 shows the sensitivity of NPV to changes in hourly wages, fuel cost, interest rate, and biochar market price. The results indicate that biochar price is the most influential variable for the financial performance of the pyrolysis operation. With a 30 percent increase in biochar price from \$2.2 to \$2.86 kg^{-1}, the NPV increases to \$43,887. The second largest influencing factor among those tested was labor cost. Increases in both interest rate and fuel cost negatively affect the NPV of the operation, but the marginal influence is lower than that of biochar price and labor cost. The values for biochar price and hourly labor wage at NPV = 0 were calculated to be \$2.73 and \$9.59 h^{-1}, respectively. For the baseline case, NPV was negative for both a fuel cost of \$0 and an interest rate of 0 percent, with the latter indicating a negative IRR (Fig. 4).

The results of the sensitivity analyses for different levels of pyrolysis productivity and conversion rate are presented in Table 4. The ranges of shift-level machine productivity and conversion rate observed in the field were used for the range of variation, and each range was divided by four to provide input values for the sensitivity analysis. The NPV estimated for the worst-case scenario was –\$536,031, where the pyrolysis system is assumed to work at the lowest observed productivity level and produce the least observed amount of biochar per unit weight of feedstock over the duration of the 10-year project period. In contrast, the best case scenario, with the highest observed productivity and conversion, generated an NPV of \$467,353. Pairs of productivity and conversion rate values for each shift are plotted along with an NPV = 0 line in Figure 5. A total of three points are located above the NPV = 0 line, indicating there were three shifts when the system worked efficiently enough to generate a positive NPV. The majority of the shifts are, however, located below the NPV = 0 line in the negative NPV zone. The wide ranges of variation in machine productivity and conversion rate also indicate that the system did not run consistently during the field study. In fact, several mechanical problems, such as reactor clogging, were experienced that slowed down the operation and thus lowered the system productivity. The most productive single shift in terms of NPV had an average productivity of 0.204 t h^{-1} with an average conversion rate of 21.8 percent, representing an NPV of \$390,406.

Table 4.—Changes in net present value (NPV) in response to different levels of pyrolysis productivity and conversion rate.

Conversion rate (%)	NPV (in USD 1,000) at productivity level (t h^{-1}): 0.114	0.141	0.167	0.192	0.219
6.3	−536.0	−500.2	−464.4	−429.8	−394.0
10.2	−422.7	−360.8	−298.9	−239.2	−177.3
14.1	−309.4	−221.4	−133.5	−48.5	39.5
17.9	−199.0	−85.6	27.8	137.2	250.6
21.8	−85.7	53.8	193.2	327.9	467.4

Discussion

Limitations of the study design

These results should be interpreted in light of several constraints related to study design. There were several occasions during which the pyrolysis system was running without generating biochar, especially when the reactor was clogged and the operators were working to resolve the problem. Because the study was designed with a clear threshold for delay focused on breaks in blower operation of 10 minutes or more, these unproductive times were not recorded as a delay in the field study. Typically, the blower

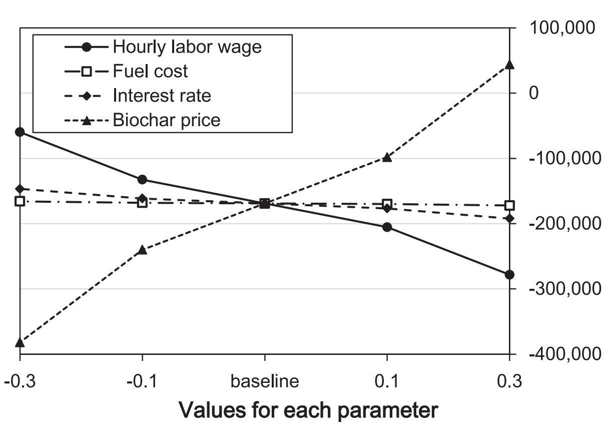


Figure 4.—Sensitivity of financial performance of the pyrolysis operation to changes in hourly labor wage, fuel cost, interest rate, and biochar market price.

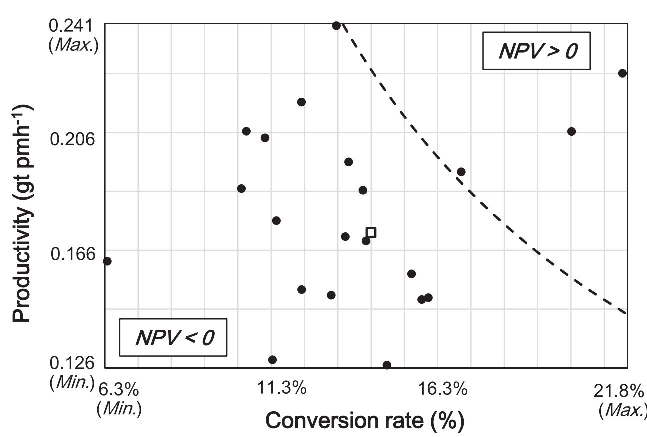


Figure 5.—Scatterplot of the observed shift-level productivity and conversion rate of the Biochar Solutions Inc. pyrolysis system.

remained on during work to unclog the reactor. A classification of these unproductive times as delay would have lowered the system's utilization rate, but increased its productivity. As a result, the measurement of productivity using productive machine hours may underestimate the potential productivity of the system using a later-model reactor design that experiences less clogging.

Another limitation in this study is that biochar production was measured only at the shift level. A constant monitoring of biochar output, assessment of temperature and pressure conditions, and measurements of productivity over shorter time periods, such as hourly, might have provided an opportunity to observe the system conditions with more resolution and thus account for cause and effect relationships leading to productivity losses. Even so, shift-level analysis is useful in quantifying productivity and financial viability. Subsequent versions of the BSI system have incorporated design elements to overcome some of the problems observed in the field—the effects of which might have been predictable with higher resolution data.

Improving operational and financial performance

The pyrolysis system used in this study produced biochar without major mechanical or technical breakdowns while operating outside under variable weather conditions for 22 working days. However, wide variation in shift-level productivity and conversion rates shows that the system did not run consistently during the observation period. In general, the results of the financial analysis indicate that the pyrolysis operation observed in this study, though technically viable, is not financially viable as a stand-alone enterprise. However, it is worth noting that the NPV for the baseline case was calculated using the gross average productivity and conversion rate obtained from this early model prototype system with high lifetime machine hours, and the system has ample opportunity for improvement in both operation and design. Furthermore, because biomass conversion is the most costly component of the operation as a whole, accounting for 79 percent of the total cost, relatively small gains in the technical and economic efficiency of the conversion process have the potential to result in large improvements in the financial viability of the enterprise.

There are two primary ways the financial viability of the pyrolysis system could be improved. First, technical and operational changes could result in higher efficiency by increasing productivity and conversion rate. Three of 22 shifts had efficiency high enough to generate a positive NPV (Fig. 5). The highest productivity and conversion rate observed at a shift level were 0.219 t h^{-1} and 21.8 percent, with an NPV of $390,406. However, these values do not represent the maximum theoretical limit of the conversion technology. The observed maximum conversion rate is still below the technical limit in this temperature range (Meyer et al. 2011), and higher productivity could be achieved through improvements in machine design and operation. Reactor clogging appeared to be one of the major mechanical issues that lowered both system productivity and conversion rate. Manually timed feeding that occurred in pulses of green feedstock entering the reactor and high moisture content in the feedstock from precipitation falling on an uncovered hopper and conveyor system also lowered the system efficiency. These problems have relatively simple technical solutions, and improvements in these areas are likely to lead to efficiency gains. The manufacturer has already sought to improve system performance through operational and design changes, such as fabricating the reactors of stronger steel that resists warping, installing paddles on the primary reactor shaft to break up the feedstock bridging that causes clogs, using a larger blower, and improving feedstock drying using waste heat and a multi-tiered dryer/conveyor rather than the single pass system used in this study. Furthermore, the feasibility of multiple units running in parallel, which has been proposed as an option to spread fixed costs over higher biochar output, was not evaluated in this study. For example, from observations it does appear that the efficiency of labor and support equipment could be improved with a multiple unit configuration.

Another way to improve financial viability is to lower the $NPV = 0$ line shown in Figure 5 to expand the positive NPV zone. This involves changes in the economic and financial environment in which the pyrolysis systems operate. A higher price of biochar through marketing and market development, including production of value-added products such as activated carbon, could increase net revenue of the pyrolysis operation and improve financial performance. On the feedstock supply side, in this analysis mill residues were considered to have a price of zero—being neither a waste output with disposal costs nor a by-product with market value, with costs incurred in processing residues into appropriate pyrolysis feedstock. If residues have disposal costs, this effectively improves the financial viability of these systems by offsetting these costs to the extent that waste production is balanced with pyrolysis capacity. Though mill residues, especially bark-free residues, have traditionally had value as raw material for pulp and wood panel manufacturing, mill closures can quickly make residues a liability in some markets.

There may be other factors that affect the position of the NPV line. Though the 4 percent risk premium incorporated into the 7 percent real interest rate used in the NPV calculations is realistic for evaluating the economic desirability of a project like this one, individual firms may have lower expectations for ventures intended to process by-products as a component of a larger manufacturing operation that produces many different value-added products. Furthermore, if distributed-scale conversion technologies become more widely deployed and proven in the forest sector, and biochar markets become more developed and less uncertain, this technology may be perceived as less risky from an investment and capital budgeting standpoint, lowering the risk premium and the corresponding real interest rate, perhaps as low as 4 percent.

In addition, value for the waste heat and energy gas from the system was not included in this analysis. Heat from the system could be used to heat buildings and kilns, offsetting fossil fuel use and associated costs. For example, the mill in this study uses propane to heat treat pallets and shipping products for export. Fossil fuel offsets may provide additional financial incentive for conversion, as well as the nonmarket benefits associated with renewable energy. Carbon sequestration represents another potential source of revenue for biochar production. Options for monetizing the value of carbon sequestration associated with biochar are evolving, but range from price premiums paid by willing retail consumers to formalized carbon offset programs and emissions trading schemes, especially those related to forestry projects, bioenergy and biofuels (Gaunt and Cowie 2009, Weisberg et al. 2010, Galinato et al. 2011).

Potential for in-woods applications

High costs of transportation and handling of feedstock often make utilization of forest residues, such as logging slash, financially unviable. As a result, these materials are often considered waste and left on site to decompose or burned in piles to reduce wildfire risk and open space for regeneration. Pile burning results in added site preparation costs for contractors. As an alternative, in-wood processing of forest biomass with a small-scale, mobile biomass conversion unit that can be deployed near the source of feedstock would generate a marketable, higher density product that could be shipped off site (Badger and Fransham 2006, Brown et al. 2013). The BSI pyrolysis system used in this study is a small-scale conversion system designed for mobility, and can be easily trailer mounted (Anderson et al. 2013). This study evaluated the system for processing mill residues in a centralized location, but future studies should also investigate in-woods applications of the system using operations research methods. With enhanced consistency in operation and higher productivity, the system has the potential to improve the utilization of forest residues that would otherwise be burned for disposal.

In addition to potential economic benefits, there may also be broader nonmarket benefits associated with this application. For example, smoke from pile burning can have negative effects on recreation and human health. These broader benefits may be effective justification for financial incentives to use in-woods thermochemical conversion as an alternative to burning, especially on public lands (Loeffler and Anderson 2014). Direct subsidy, tax incentives or incentivized stewardship contracting for biomass utilization would obviously improve the financial viability of the pyrolysis operation to some extent, especially for early adopters of these technologies.

In-woods deployment of conversion technology is not without challenges. There could be additional feedstock handling and preparation costs. Unlike mill residues, logging residues are usually spread over multiple timber harvest areas and are frequently contaminated with soils. The heterogeneous particle size and composition of forest residues would also increase handling and screening costs if feedstock specifications for the system are narrow in terms of particle size, ash content, and moisture content. In addition, fixed mobilization costs of the pyrolysis system and associated support equipment, as well as difficult accessibility to electric power and maintenance support (e.g., engineering and fabrication personnel) would likely cause an increase in operational costs compared to sawmill deployment. However, the current pyrolysis system has significant room for mechanical and operational improvements that would potentially make the system financially viable for in-wood applications.

Conclusions

At the productivity and conversion rates observed, it is unlikely that the operation described here would be financially successful as a stand-alone enterprise. However, results show clear opportunities for technical and operational improvements that would increase the financial viability of this system. This research can be applied to other equipment and settings because it is based on generalized machine rates and standard project evaluation techniques. As distributed-scale thermal conversion becomes more widely deployed, financial and economic analysis grounded in operations research can be used to inform supply chain logistics, investment decisions and public policy.

Acknowledgments

The authors would like to thank Biochar Solutions Inc. and Pueblo Wood Products, especially Jonah Levine and Brad Dunmire, for participating in this study and generously providing time, resources, and information. Dan McCollum, Dan Loeffler, and Edward Butler assisted with field operations and data collection. This research was funded by a Woody Biomass, Bioenergy, and Bioproducts grant from US Forest Service Research and Development, with significant cost match and in-kind support from the University of Montana, Biochar Solutions Inc., and Pueblo Wood Products. Additional support was provided by the Biomass Research and Development Initiative of the USDA National Institute of Food and Agriculture.

Literature Cited

Anderson, N., D. Page-Dumroese, J. G. Jones, D. McCollum, S. Baker, D. Loeffler, and W. Chung. 2013. A comparison of producer gas, biochar, and activated carbon from two distributed-scale thermochemical conversion systems used to process forest biomass. *Energies* 6:164–183.

Anex, R., A. Aden, F. Kazi, J. Fortman, R. Swanson, M. Wright, J. Satrio, R. Brown, D. Daugaard, A. Platon, G. Kothandaraman, D. Hsu, and A. Dutta. 2010. Techno-economic comparison of biomass-to-transportation fuels via pyrolysis, gasification, and biochemical pathways. *Fuel* 89:S29–S35.

Antal, M. J., Jr. and M. Gronli. 2003. The art, science, and technology of charcoal production. *Ind. Eng. Chem. Res*. 42(8):1619–1640.

Azargohar, R. and A. Dalai. 2006. Biochar as a precursor of activated carbon. *Appl. Biochem. Biotechnol*. 131:762–773.

Badger, P., S. Badger, M. Puettmann, P. Steele, and J. Cooper. 2011. Techno-economic analysis: preliminary assessment of pyrolysis oil production costs and material energy balance associated with a transportable fast pyrolysis system. *BioResources* 6(1):34–47.

Badger, P. and P. Fransham. 2006. Use of mobile fast pyrolysis plants to densify biomass and reduce biomass handling costs—A preliminary assessment. *Biomass Bioenergy* 30:321–325.

Biochar Solutions Inc. (BSI). 2011. BSI biochar base unit: Technical specifications v 3.0. Biochar Solutions Inc., Carbondale, Colorado.

Bridgewater, A. 2003. Renewable fuels and chemicals by thermal processing of biomass. *Chem. Eng. J*. 9:87–102.

Bridgewater, A. 2004. Biomass fast pyrolysis. *Therm. Sci*. 8(2):21–50.

Briens, C., J. Piskorz, and F. Berruti. 2008. Biomass valorization for fuel and chemicals production—A review. *Int. J. Chem. Reactor. Eng*. 6(1):1–49.

Brinker, R. W., J. Kinard, B. Rummer, and B. Lanford. 2002. Machine rates for selected forest harvesting machines. Circular 296 (revised). Alabama Agricultural Experiment Station, Auburn University, Auburn.

Brown, A., P. Brady, C. Mowry, and T. Borek. 2011. An economic analysis of mobile pyrolysis for Northern New Mexico forests. Report no. SAND2011-9317. Sandia National Laboratories, US Department of Energy, Albuquerque, New Mexico.

Brown, D., A. Rowe, and P. Wild. 2013. A techno-economic analysis of using mobile distributed pyrolysis facilities to deliver a forest residue resource. *Bioresour. Technol*. 150:367–376.

Davis, R., A. Aden, and P. Pienkos. 2011. Techno-economic analysis of autotrophic microalgae for fuel production. *Appl. Energy* 88: 3524–3531.

Duff, S. and W. Murray. 1996. Bioconversion of forest products industry

waste cellulosics to fuel ethanol: A review. *Bioresour. Technol*. 55(1):1–33.
Galinato, S., J. Yoder, and D. Granatstein. 2011. The economic value of biochar in crop production and carbon sequestration. *Energy Policy* 39:6344–6350.
Gaunt, J. and A. Cowie. 2009. Biochar, greenhouse gas accounting and emissions trading. *In:* Biochar for Environmental Management: Science and Technology. J. Lehmann and S. Joseph (Eds.). Earthscan, London. pp. 317–340.
Hamelinck, C. N. and A. Faaij. 2006. Production of methanol from biomass. *In:* Alcoholic Fuels. S. Minteer (Ed.). Taylor and Francis Group, New York. pp. 7–49.
Kumar, A., D. Jones, and M. Hanna. 2009. Thermochemical biomass gasification: A review of the current status of the technology. *Energies* 2(3):556–581.
Loeffler, D. and N. Anderson. 2014. Emissions tradeoffs associated with cofiring forest biomass with coal: A case study in Colorado, USA. *Appl. Energy* 113:67–77.
Meyer, S., B. Glaser, and P. Quicker. 2011. Technical, economical, and climate-related aspects of biochar production technologies: A literature review. *Environ. Sci. Technol*. 45:9473–9483.
Miyata, E. 1980. Determining fixed and operating costs of logging equipment. General Technical Report NC-55. USDA Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota. 20 pp.
Mohan, D., C. Pittman, Jr., and P. Steele. 2006. Pyrolysis of wood/biomass for bio-oil: A critical review. *Energy Fuels* 20:848–889.
Olsen, E., M. Hossain, and M. Miller. 1998. Statistical comparison of methods used in harvesting work studies. Research Contribution 23. Forest Research Laboratory, College of Forestry, Oregon State University, Corvallis. 45 pp.
PHG Energy. 2011. Downdraft gasification alternative renewable energy technology, PHG Energy. PHG Energy, Nashville, Tennessee. www.phgenergy.com. Accessed May 30, 2012.
Sorenson, C. B. 2010. A comparative financial analysis of fast pyrolysis plants in Southwest Oregon. Master's thesis. University of Montana, Missoula. 104 pp.
Tijmensen, M., A. Faaij, C. Hamelinck, and M. van Hardeveld. 2002. Exploration of the possibilities for production of Fischer Tropsch liquids and power via biomass gasification. *Biomass Bioenergy* 23:129–152.
US Department of Agriculture (USDA). 2005. Forest Residue Trucking Simulator (FoRTS) v. 5. Forest Operations Research Unit, USDA Forest Service, Southern Research Station, Auburn, Alabama. www.srs.fs.usda.gov/forestops/products/tools.html. Accessed May 30, 2012.
US Federal Register. 2013. U.S. Federal Register 78 FR 16706. Change in Discount Rate for Water Resources Planning. www.gpo.gov/fdsys/granule/FR-2013-03-18/2013-06177. Accessed September 9, 2014.
Uslu, A., A. Faaij, and P. Bergman. 2008. Pre-treatment technologies, and their effect on international bioenergy supply chain logistics. Techno-economic evaluation of torrefaction, fast pyrolysis and pelletisation. *Energy* 33:1206–1223.
van der Stelt, M., H. Gerhauser, J. Kiel, and K. Ptasinski. 2011. Biomass upgrading by torrefaction for the production of biofuels: A review. *Biomass Bioenergy* 35:3748–3762.
Weisberg, P., M. Delaney, and J. Hawkes. 2010. Carbon market investment criteria for biochar projects. Publication no. CEC-500-02-004. California Energy Commission, Sacramento.
Wright, M., D. Daugaard, J. Satrio, and R. Brown. 2010. Techno-economic analysis of biomass fast pyrolysis to transportation fuels. *Fuel* 89:S29–S35.